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COLD FORMED FROM STRIP AND SHEET

The Copper Development Association, sponsored by the copper industry, is a non-trading organisation the aim of which is to encourage the use of copper and its alloys and to promote their correct and efficient application. It provides a link between research and industry. Its services, which are available to all without charge, provide technical information and advice as well as a wide range of useful publications. It maintains close contact with similar associations in Europe and other parts of the world.

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COLD FORMED FROM STRIP AND SHEET

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FOREWORD

Copper, brass and other copper alloy strip and sheet are widely used for the manufacture of pressings and other products required in engineering and general industry.

This book (which was originally prepared by Mr. H. J. Miller, M.Sc., at that time the Association's Metallurgist), is chiefly devoted to a consideration of some of these uses, together with the properties of the materials. An outline of some of the more important metal-working operations is also included.

While much of this information may be quite common knowledge to those engaged in everyday production of strip and sheet metal articles, it is hoped that it will be of interest to the general body of engineers and others who are concerned with the specification and ultimate use of such products.

Other applications of copper and its alloys are dealt with in separate publications of the Copper Development Association. These are listed at the end of this book and are available free of charge to anyone giving evidence of responsible status or genuine interest.

Further information will be given on application.

L. BERNHARDT
November, 1958

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Section 1.

GENERAL INTRODUCTION

Copper and copper alloys are extensively used for general presswork and other metal working operations chiefly because they combine in a unique manner overall low cost with excellent working properties, good mechanical strength and resistance to corrosion; they cannot rust. Moreover, in strip and sheet forms, copper alloys may be obtained within close dimensional tolerances and possessing a very good surface finish, so that they are particularly suitable for repetition presswork and other operations which necessitate careful attention to these factors. Additional advantages result from the choice of copper and copper alloys when polishing and plating are subsequently to be performed, for they can be plated very easily and cheaply and are, in fact, ideal materials for this purpose.

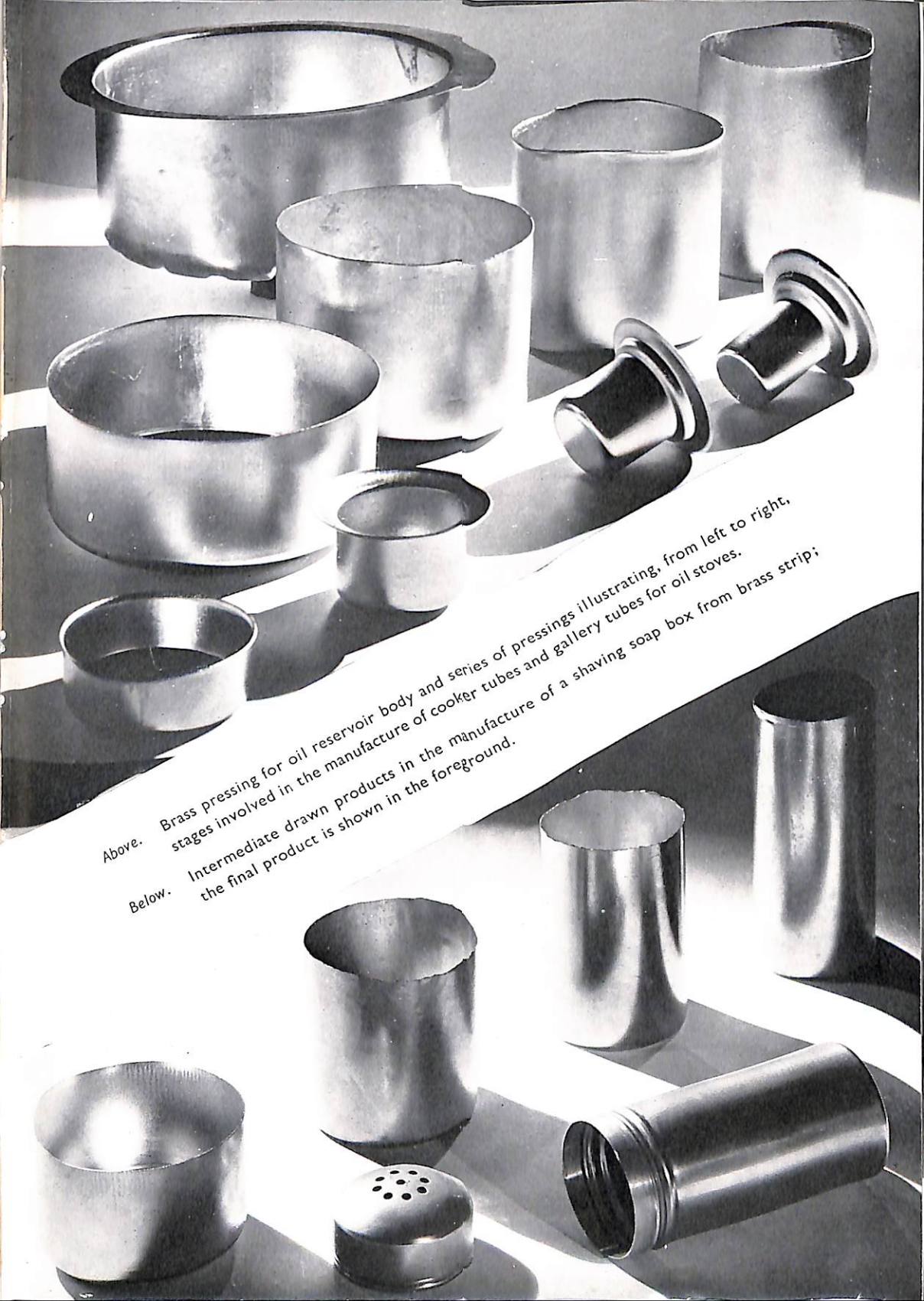
It is difficult to describe adequately the wide range of products obtained from copper alloy strip and sheet material, but in the photographs included in the subsequent pages of this book a number of typical examples are shown. These products have been manufactured by many different working methods, and information upon some of the more fundamental processes is given in Section 2. The illustrations are only intended to convey some idea of the wide use of copper and copper alloy strip and sheet in engineering and other industries, and doubtless numerous other applications will occur to the reader.

In Section 3, commencing on page 55, a general description is given of the types and properties of copper alloys in strip and sheet forms. Although a wide range of these alloys is employed for the manufacture of various products, by far the most widely used materials are the brasses of copper contents ranging between 63 per cent. and 70 per cent. Brasses are not the cheapest materials available to manufacturers but they often prove the most economic when the all-in cost of the finished products is considered; this is particularly the case when the components are small and many fabricating processes are involved, or when a plated finish is required.

Among all the desirable attributes of copper alloys, resistance to corrosion is perhaps the most important, and is often the determining factor in the choice of material for a particular purpose. Although electroplated steel articles may appear to be quite satisfactory at first, porosity or local damage may lead to rapid rusting, accelerated by galvanic action between the plated metal and the steel. This contingency can be eliminated by the use of copper-base alloys, either with or without subsequent electroplating.

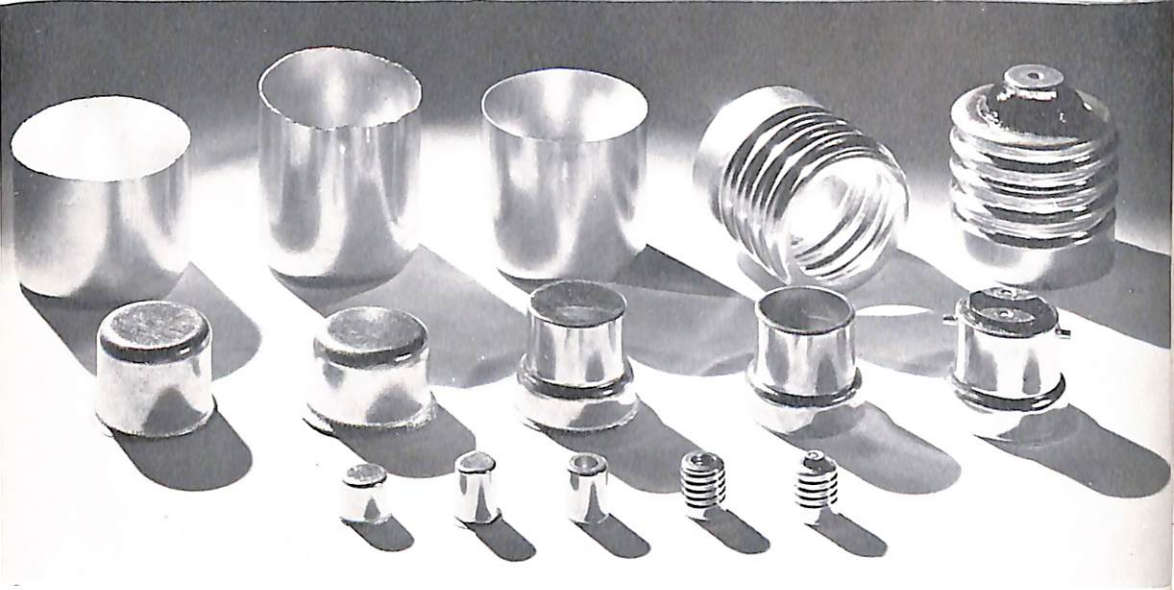
The general working properties of copper alloys are such that it is easier to produce articles from them than from ferrous materials, with a consequent saving in production cost. The higher ductility of the copper alloys, the reduced power required for deformation, the adoption of higher speeds of working, and the smaller number of operations owing to the greater reductions which may be made, all contribute to economical production, and it is frequently possible to obtain complex shapes which are obtainable only with extreme difficulty and at high cost from other materials. The working properties of brass are such that it can be drawn on power presses at two or three times the speed of ferrous materials and there is diminished wear on the tools, owing to the less likelihood of "fouling"; this means that frequent tool changing is avoided, hence the fabrication costs are very much reduced.

A further factor, which should be strongly borne in mind, is that the waste material, when working with copper, brass and other copper alloys, has considerable scrap value, and this also contributes in no small measure to their favourable competitive position.



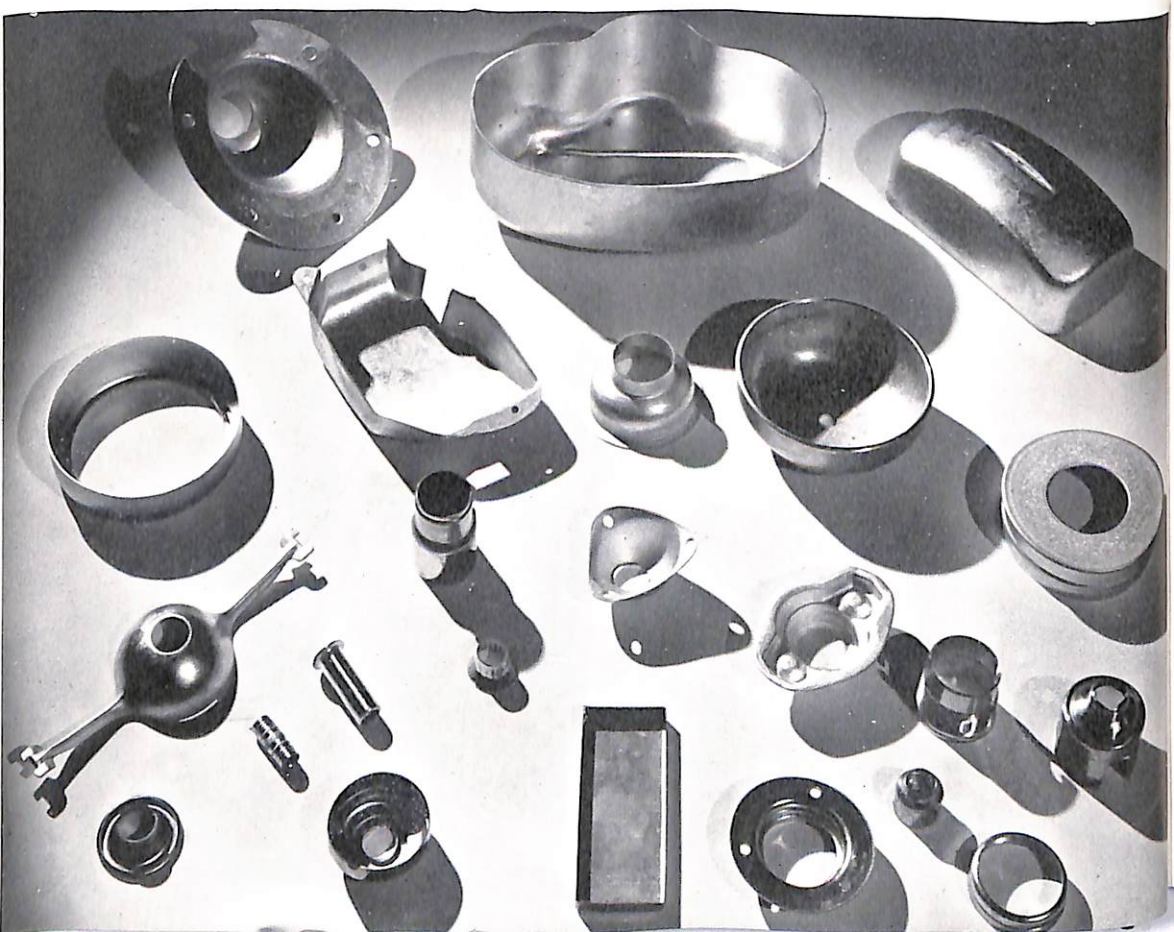
Above. Brass pressing for oil reservoir body and series of pressings illustrating, from left to right, stages involved in the manufacture of cooker tubes and gallery tubes for oil stoves.

Below. Intermediate drawn products in the manufacture of a shaving soap box from brass strip; the final product is shown in the foreground.



Above. Stages in the production of electric lamp caps from brass strip.

Below. Miscellaneous pressed products used in automobile, electrical and other engineering industries.



Section 2.

PRINCIPAL PROCESSES EMPLOYED IN THE MANUFACTURE OF STRIP AND SHEET PRODUCTS.

SHEARING OPERATIONS.

Cutting, or shearing, is involved in the production of almost every article made from sheet or strip metal. Shearing operations include blanking, piercing, notching and slitting, but the most important from the present point of view is that of blanking by means of a punch and die. The die is usually stationary and supports the strip, while the punch is the moving member.

By means of blanking operations, products of any desired shape, such as circles, rectangles, etc., are obtained, although in some instances simple shapes may be produced by other methods, such as line shearing in a guillotine or shearing on two sides of a rectangle simultaneously. Both the quantity involved as well as the size and shape determine whether blanking or other means of cutting is to be adopted. Circles up to about 4 in. diameter are almost invariably produced by means of blanking presses; when circles of greater diameter are to be obtained from thin strip material (about $\frac{1}{32}$-in. thickness or less) they are frequently cut from rough square shapes on a revolving table by rotating shearing cutters, although if large quantities are involved, blanking may again be the more economical method. For large-diameter discs exceeding a thickness of about $\frac{1}{32}$-in., blanking is generally used.

In blanking, the stresses must be evenly distributed around the periphery, and this is ensured by careful attention to the dimensions and " setting-up " of the punch and die. If the tools employed are of unsuitable design or incorrectly " set-up," then defects are obtained which may adversely affect subsequent working operations. For instance, with blanks possessing burred edges, there is interference of natural flow of the metal in the course of subsequent drawing processes, so that the stresses are increased and may result in tearing or

splitting of the product. It is therefore essential that the tools used for blanking and other metal shearing operations should be exactly adapted for the operations involved, and of the factors which determine this suitability the question of clearance between the punch and die is perhaps the most important.

Clearance between punch and die.

The clearance between punch and die is normally defined as the width of the gap between them. The effect of clearance on the shearing of metal bars of $\frac{1}{2}$ in. thickness has been investigated by Chang and Swift,[37] the following being among their conclusions:—

> The provision of clearance has the effect of (*a*) introducing an element of initial bending, (*b*) generally increasing the volume of material involved in the process, and (*c*) introducing tensile conditions in the later stages of the operation.
>
> Nevertheless, owing to the natural obliquity of incipient cracks, a clearance can be found with materials subject to crack formation, which will cause a natural confluence of the cracks and consequently produce a clean severance with a minimum of strain work.
>
> The optimum clearances suggested for the metals tested, in the light of these considerations and the experimental results, are approximately as follows:—
>
> Annealed 70/30 Brass—clearance 0 to 5 per cent. of metal thickness.
>
> Hot rolled oxygen-bearing copper—clearance 0 to 10 per cent. of metal thickness.

Chang and Swift tested two types of hot-rolled oxygen-bearing copper of identical composition but of different physical condition. They found that the sample with a grain size of 0·04 mm. and a D.P. hardness value of 100 required no clearance, whereas for the sample having an average grain size of 0·065 mm. and a D.P. hardness value of about 75 the optimum clearance was 5 to 10 per cent.

While it appears desirable to establish by tests the effects of temper, composition and thickness, the most suitable clearance, in the case of copper and copper alloys, has for many years been accepted as being 5 per cent. of the metal thickness.

Pressure required for shearing and blanking.

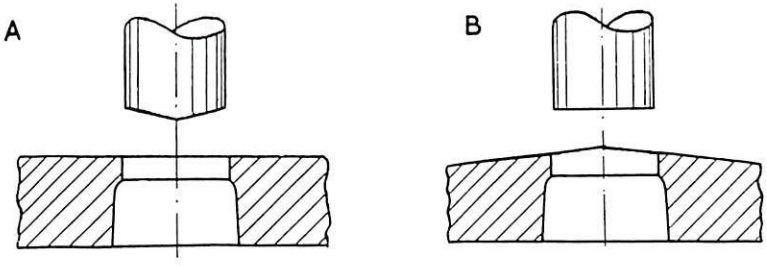
The pressure required for cutting metal strip by means of a punch and die, provided with the correct clearance, is expressed by means of the formula:— P (lb.) = L × *t* × S.

L is the length of cut in inches, *t* is the metal thickness (ins.), and S is the shearing strength (lb./sq. in.). For brass strip the shearing strength may be accepted as 35,000 lb./sq. in. for annealed metal and 55,000 lb./sq. in. for hard rolled material, although quantitative values for shearing strength are only approximate. The variations of shearing strength with rolling reduction for copper and 70/30 brass are given in a paper by Cook and Richards. [78]

The pressure required for cutting is increased if the cutting edges of the tools are at all dull, and this is especially true when the strip is thin. Variation of the clearance, from the amount which is most satisfactory from a cutting point of view, to zero, results in an increase of pressure of from 5 to 10 per cent., whereas the pressure is decreased approximately 20 per cent. by providing either the punch or the die with an angle—often called "shear"—as discussed below.

Shear on punches and dies.

The load on the press may be reduced, though the working stroke is lengthened, by grinding the flat face of either the punch or die at an angle with reference to the other. This cutting angle is generally quite small, amounting only to about 10°, and should always be used when cutting thick strip; with thin strip, of less than 12 S.W.G. thick-



Blanking—shear on punch (A) or die (B).

ness, the faces of both the punch and the die should be left flat. The provision of the above-mentioned shear on the tools results in distortion

of the metal, so that when the perforated strip is required to be left in a flat condition the die should be ground flat and the punch ground with the necessary " shear," as indicated in sketch A, p. 11. On the other hand, when the blanks are required flat, the " shear " must be put on the die and the punch left flat, as indicated in sketch B.

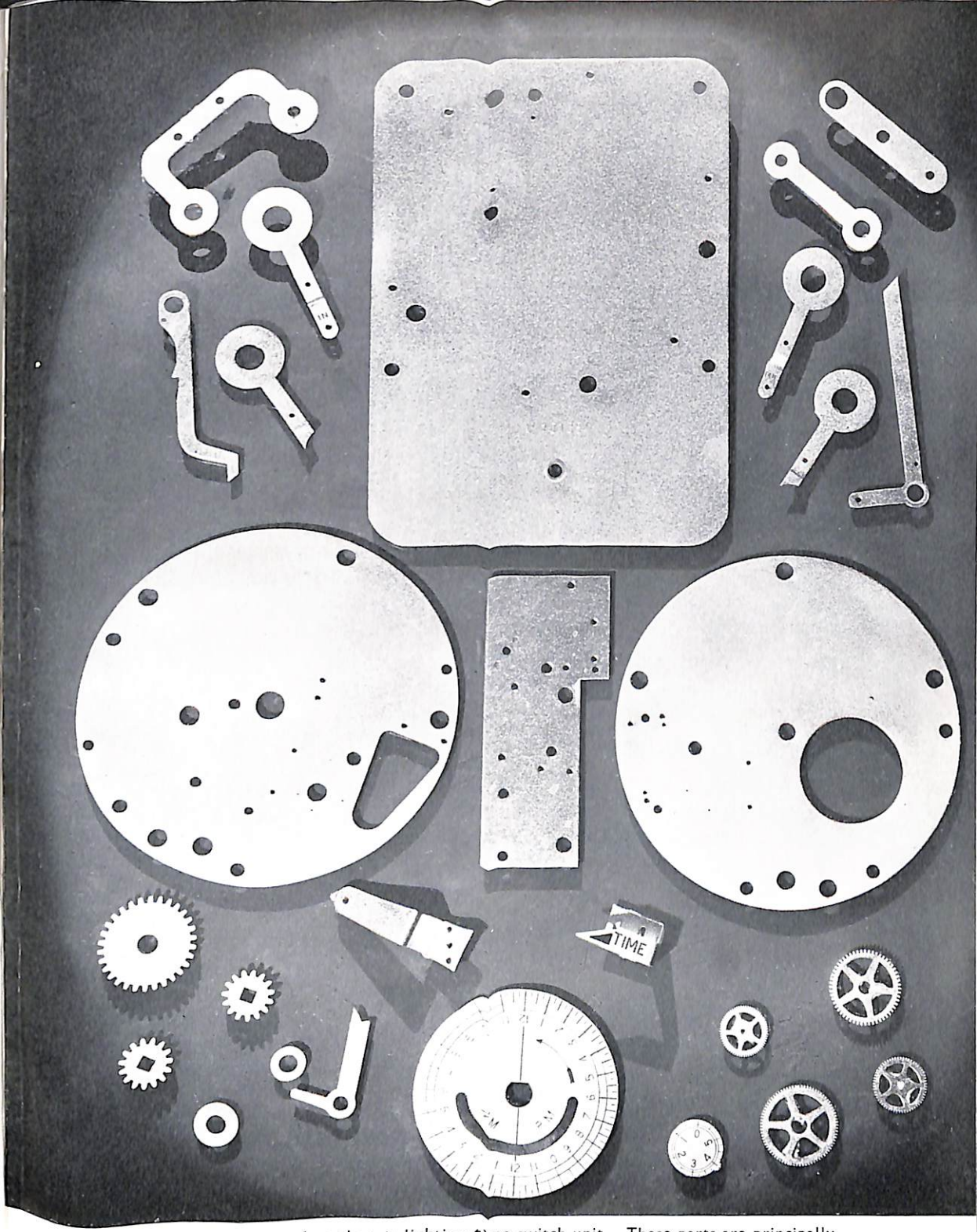
Machines, tools, and set-up for blanking, etc.

The machines employed in blanking operations should be of ample pressure capacity to effect shearing of the material, and moreover they should be of robust construction in order to secure rigidity of the tools and thus prevent misalignment during working. Blanking is generally carried out in presses of the camshaft type, although other forms may be used.

The blanking tools are generally made from oil-hardened and tempered alloy steels and, as already mentioned, particular care must be exercised regarding the preparation and maintenance of the cutting edges. While small tools are usually made entirely from one piece of steel, the use of hardened inserts, which form the actual cutting edges, is a very prevalent practice in the manufacture of larger tools.

In most types of machines the punch is made the moving member, although there are a few instances of machines employing stationary punches. The height or distance through which the punch normally moves in the course of its cutting stroke is largely governed by the construction of the machine and thickness of metal strip, but there is no advantage to be gained from an excessively long stroke; in fact there is added difficulty in securing satisfactory support and guidance. As a general rule the stroke should not be less than about 5 times the thickness of the strip being cut and should not exceed 15 times its thickness, except in the case of material of less than about 0.050 in. thickness, when the proportionate stroke may have to be very much greater. The punch should on no account be made long in comparison with its diameter, owing to the possibilities of deflection and consequent inaccuracy.

As essential adjuncts to the tools, there are guides to ensure correct positioning of the strip, strippers to prevent webbing scrap from clinging to the punches, means for disposal of the blanks, and in some



Component parts of an electric lighting time-switch unit. These parts are principally produced by blanking, piercing and notching processes.

cases guide pins to secure alignment of the tools during working, while for large outputs and rapid production, automatic feeding arrangements for delivering the strip to the machine must also be provided.

For notching, piercing and analogous operations, as performed for instance upon clock, electric meter and other components, of the type shown on p. 13, the principles adopted are of a very similar nature to those outlined for blanking operations. In certain cases it is possible to punch holes of diameter approximating to the thickness of the strip material.

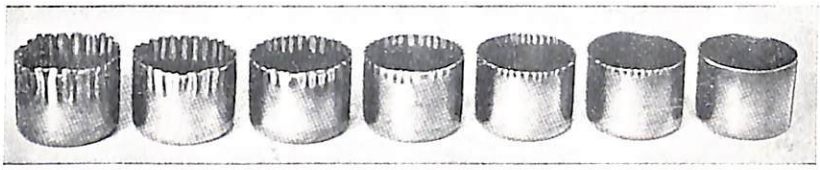
The limits of accuracy of blanking, piercing, notching and other operations are clearly controlled by the accuracy with which the tools have been prepared, together with other factors such as the limitations of the machine and setting-up of the tools; wear contributes very much to the tolerances required in actual production. In piercing operations, as carried out upon small instrument parts, it is possible to work to an accuracy of 0.0002 in.

CUPPING OPERATIONS.

Amongst the most common operations to which blanks are subjected are those of cupping and subsequent drawing. In cupping, the blanks are formed into cup shapes and the operations involved may consist of simple folding (*i.e.* bending up all round with consequent thickening at the open end of the cup) and, in addition, the cylindrical portion and base of the cup may be thinned in varying degrees. In very few instances is it necessary to resort to the maximum amount of working which the material can withstand. It is possible under certain favourable conditions to obtain, in one operation, brass cups of diameter somewhat less than half that of the original blanks, and in which the height exceeds the diameter. The modern tendency in presswork practice, however, particularly with multiple stage machines, is to perform smaller reductions at greatly increased speeds rather than to effect the maximum amount of work and risk occasional breakdowns. For rectangular and other complex shapes which neces-

sarily involve severe local working it is not possible to effect such large overall amounts of deformation (see pp. 31, 32).

The essential tools for cupping operations consist of a die, a blankholder or pressure plate and a punch. The function of the blankholder is to prevent wrinkling (or puckering) of the metal. With thick material



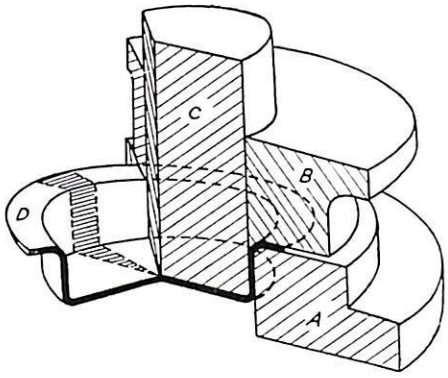
P = 220 264 331 375 441 529 639 (lb.)

Influence of blankholder pressure on wrinkle formation.[2]

wrinkling does not occur so readily and the blankholder may then be dispensed with, particularly if the diameter of the blank is not much larger than that of the die. However, the necessity for a blankholder in the working of thin strip will be appreciated from the photograph above, which shows a series of cups produced from the same set of tools with different pressures upon the blankholder. At low pressures there is excessive wrinkling which is progressively diminished by increase of the blankholding pressure.[2] For most copper alloys blankholder pressures vary between 150 and 300 lb./sq. in. Higher pressures may be required for the stronger alloys, but excessive pressures give rise to tearing.

Sommer[1] has illustrated cupping operations by means of the sketch on p. 16, showing the forming of a round shell. Part of the shell and also of the tools has been cut away. The blankholder or pressure plate descends first and holds the blank in its correct position upon the top face of the die before the punch commences its downward stroke. As the metal is drawn towards the centre of the die, it is compressed in the peripheral direction and consequently tends to thicken, particularly near the edge of the blank. This peripheral compressive stress is accompanied by radial tension which is greatest at the throat of the die.

The cylindrical portion of the cup is of course subject to longitudinal tension. The shaded portion in the sketch represents a small sector



Diagrammatic representation of cupping operation.

A. Part of drawing die.
B. Blankholder.
C. Drawing punch.
D. Partly drawn shell.

of the initial blank and, while this largely retains its original dimensions at the base, it is formed into a part-cylindrical shape as the metal is drawn from the flange into the wall.

Generally, the metal in contact with the flat end of the punch is only thinned slightly, as it is carried through the die without appreciable deformation. The outer portion of the blank is subjected to the greatest amount of deformation, as it is first thickened while being reduced in diameter in coming towards the centre of the die. This gradual increase of thickness of the outer portion of the blank before entering the die—amounting to about 40 per cent. when the cup diameter is half the blank diameter—not only necessitates a considerable increase of pressure on the punch, but may also interfere with the flow of metal into the die to such an extent that fracture occurs in the walls of the product. This tendency can be offset by means of a sloping face upon the top of the die; the slope down towards the orifice should, however, be very little, say of the order of 1° to 5°. The advisability of working with materials which possess a combination of extremely good ductility and high strength—the latter being necessary to avoid tearing—will be clearly apparent and in this connection brass offers unique advantages.

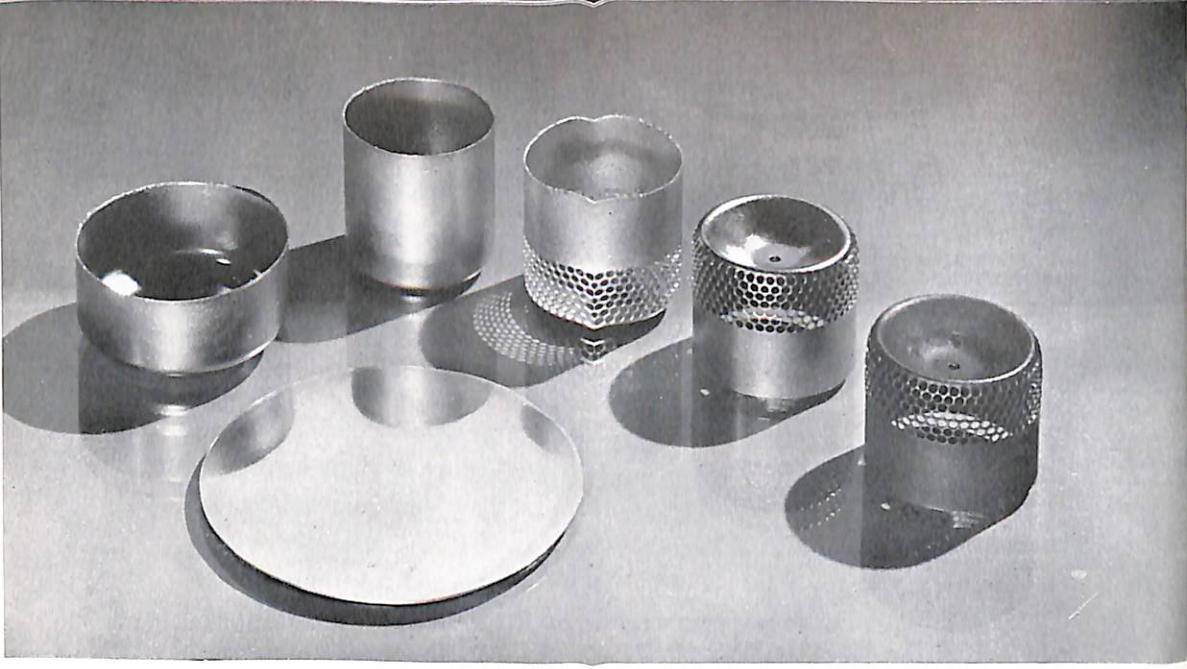
Shape of punch and die.

The dimensions and shapes of the punch and die are determined by the shape of the ultimate products, but wherever possible, this should be so proportioned that minimum resistance to the flow of metal is involved in the cupping operation.

A characteristic of cups drawn with normal ratios of blank to cup diameter (drawing ratios) is that two distinct zones of thinning exist, one in the cylindrical wall near the punch profile radius and the other somewhere on this radius. If the latter is too small, rupture may occur in these regions. On the other hand, with large punch profile radii, there is more general thinning over the base, but this may be desirable when cups of great depth are to be drawn. The least amount of thinning near the nose of the punch probably occurs when the punch profile radius is moderate, i.e. from about one-eighth to one-quarter of the punch diameter. While the punch profile radius does not appreciably affect either the maximum load or the energy required for the operation, the more generous this radius, the more gradually rises the punch load and the longer becomes the stroke of the punch.

A small radius of curvature of the working shoulder of the die not only causes the punch load to develop quickly but, in this case, the maximum load reached (and therefore the danger of tearing) and the total energy required are greater. If, on the other hand, the die profile radius considerably exceeds ten times the blank thickness, wrinkling of the metal is probable. When dealing with strip and sheet of $\frac{1}{64}$ in. to $\frac{1}{32}$ in. thickness, the die profile radius should be about ten times the metal thickness and may be somewhat larger for very thin strip. In the case of heavier gauges, the die profile radius may be reduced to four or six times the metal thickness.

In order to reduce the resistance to the flow of metal as much as possible, it is advisable to remove all circumferential markings from both the die and the pressure plate, and to give the final polishing in the



Stages in the manufacture of a flame spreader as used in special paraffin burners. The material is "Kunial" brass (see p. 58). The first cupping operation is followed by annealing, redrawing, perforating, pierce-forming of the top, trimming, and precipitation hardening.

direction of the flow of the metal. The necessity of avoiding burred edges upon the blanks to prevent uneven drag, from the pressure plate, has already been mentioned.

Punch and die sizes determine wall thickness.

The difference between die and punch radii, frequently referred to as clearance, determines the wall thickness of drawn products. Where it is desired to effect simple folding or cupping, the radial clearance should be made from 20 to 40 per cent. greater than the thickness of the blanks in order to allow for thickening of the latter, to which reference has already been mace. If, in addition to cupping, the metal is to be thinned or " ironed," the clearance must be less, corresponding to the amount of drawing required. This superimposes a drawing operation upon that of folding and it is frequently an advantage when heavy amounts of work are performed and the wall thickness is to be reduced markedly, to resort to the use of dies possessing two working shoulders; by this means the work is divided so that folding takes place at the first shoulder and thinning or " ironing " at the second. Ironing is generally applied only to relatively thick material.

The reduction which can be carried out upon brass and other copper alloy strip varies very much with the metal thickness, and greater reductions may be made with thick than with thin material. However, owing to the hardening which occurs in the folding stage of the process, it is advisable in producing round cups to limit the reduction of metal thickness to about 10 per cent. For the manufacture of products requiring greater reductions it will be necessary to resort to two or more operations of the type considered on pages 28-31, and also to anneal at the intermediate stages as outlined on page 47.

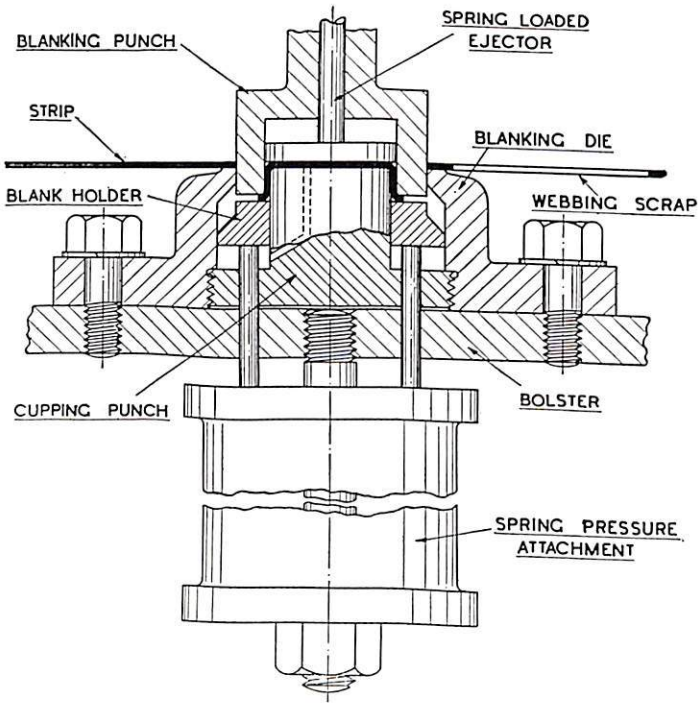
Machines and tools for cupping operations.

For the production of cups from sheet and strip metal or blanks, four essentially different methods involving different types of tools may be adopted. The simplest and oldest of these is performed by means of single-acting machines, and blanks which form the initial supply are fed to the cupping tools either by hand or mechanically.

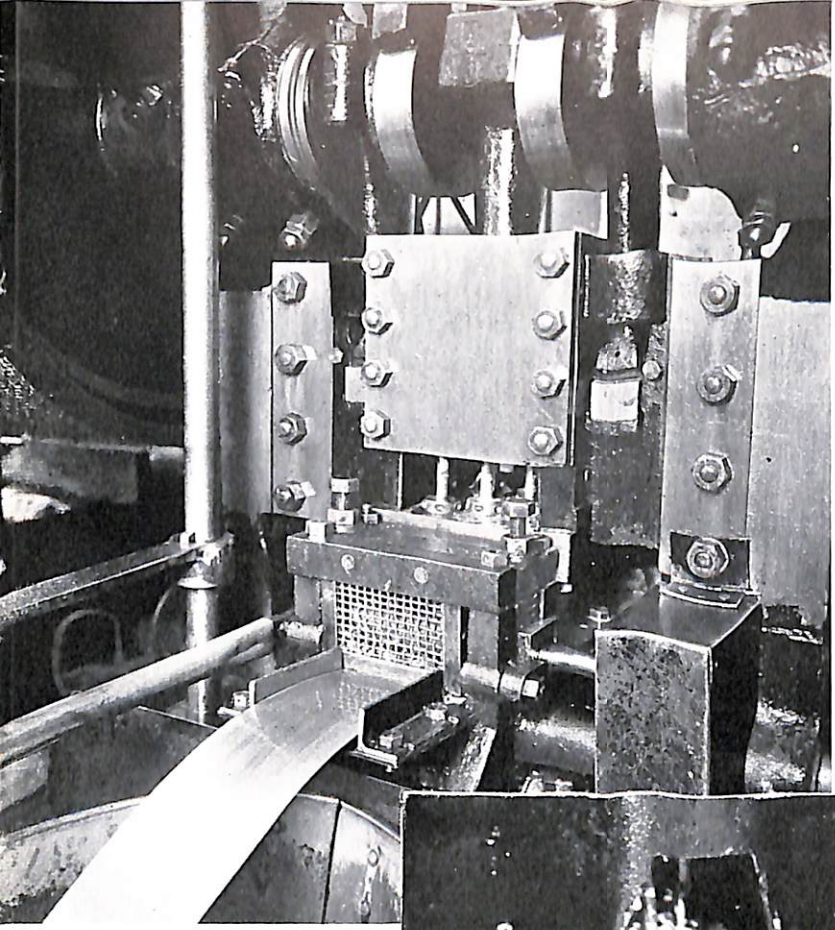
The second method involves the use of double-acting presses. These perform both blanking and cupping from metal strip which is fed by manual or mechanical means. In such presses the cupping punch operates concentrically within the blanking punch, while the die is of a compound type, designed to perform first the shearing and then the cupping stages. The stroke of the blanking punch must be capable of careful adjustment, as it is required also to play the part of a blank-holder or pressure plate during the actual cupping stage. Generally in this type of machine the operations are carried out in the vertical position and the products are pushed through the cupping dies, being stripped from the punch by the bottom face of the die or by the assistance of an extraction box. In order to speed up production, and also to reduce the amount of webbing scrap, it is quite common practice to blank and cup several products at each stroke of the machine, this being made possible by the provision of multiple punches so positioned that the minimum amount of strip metal is wasted. In fact, the total area of strip material required for a given blank can be progressively reduced as the number of products per stroke is increased. This practice is only applicable to large-scale production, and as there may be difficulties in securing satisfactory functioning of all the tools at

the same time, there is a limit to the number which can be operated. A typical double-action press for blanking and cupping five products at each stroke is illustrated on page 21 opposite.

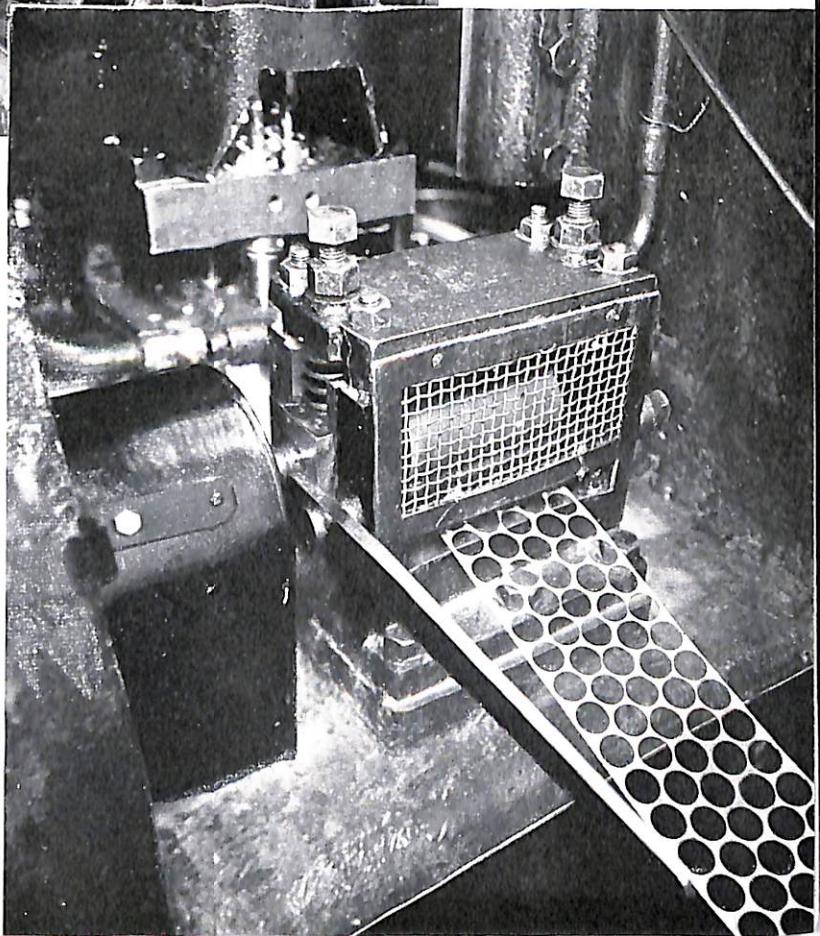
The third method again uses a single-acting press but the tools are of " combination " type, and by this means it is possible to blank and cup thin strip material in the one operation. Generally the machines are set at an angle so that the resultant cups may slide away by gravity, but if the machines are built in a vertical position, means for removal of the products must be provided. The functioning of combination tools of the type shown in the diagram below is dependent upon the blanking punch having a recess, which forms the actual cupping die. During the complete stroke of the machine this tool first cuts the blank and then, in conjunction with the blankholder and the stationary cupping punch, forms the cup. The blankholder is carried



Combination tools for blanking and cupping.



Left.
Double action press for blanking and cupping, showing strip being fed into the machine.



Right
Webbing scrap issuing from back of the machine.

upon a spring attachment (or it may be actuated pneumatically) so that it is depressed when the blanking punch descends. A spring-loaded ejector, operating inside the blanking punch, removes the products from the cupping die. Various refinements to the design, as shown, are possible; for instance, a cutting ring may be fitted under a shoulder of the cupping punch, thus causing the flange of the shell to be pinch-trimmed at the end of the stroke of the machine. Combination tools are widely used, as they may be operated very simply, but their application is limited to light gauge materials.

In the fourth method a triple-acting machine is employed and by its use it is possible to carry out blanking, cupping and indenting or embossing operations at each stroke. In principle it is very similar to that of the double-acting machine, but the cupping punch carries the product through the die and then strikes another punch or head moving in the opposite direction. By this means the head of the cup is squeezed between the two punches and receives the desired impressions. Triple-action machines are generally set at an angle so that the products may fall away by gravity.

The foregoing description of the methods of obtaining cups from strip products merely covers the principles which are involved. Naturally, for rapid and smooth production, the machines possess many refinements, the necessity for which will be appreciated when it is borne in mind that modern machines may, for some components, be operated at speeds ranging up to 200 strokes per minute, while speeds of more than 1,000 strokes per minute may be attained in ultra high-speed presses. Where the products cannot conveniently be trimmed in the cupping press, this may be done on special machines, such as, for instance, flat-edged trimming presses. A slide in the bed of these machines imparts a lateral motion in several directions to the lower die, thus shearing the scrap squarely around the top of the cup.

Lubrication.

Perhaps one of the most important points, especially in connection with modern high-speed machines, is the necessity of providing adequate lubrication of tools and metal. For hand-operated and other slow-speed machines lubrication is not so important and it is often sufficient to

apply somewhat indifferent lubricants at occasional intervals, whereas high-speed machines require a continuous supply of suitable lubricant. This functions partly as a coolant, but it must also have lubricating properties and so prevent actual metal to metal contact. One of the principal problems associated with increases of speed of machines has been in connection with lubricants, for at the higher speeds of working the lubricant films tend to break down and this may result in actual contact between the tools and the metal being worked, so that there is rapid wear of the tools; also, what is perhaps more important, there may be scoring of the products owing to " fouling " of the tools.

The ideal condition is, of course, to have a definite film of lubricant between the tools and the metal, but the practical attainment of this is a difficult matter, and, although many useful studies of lubrication problems have been made, information upon the subject is still far from complete. One of the most widely used lubricants is a soap solution and this is often used hot, as it has been shown that its lubricating properties are then superior; it would seem that this liquid acts mainly as a coolant, but it also acts in a lubricating capacity. Advantages are sometimes obtained by the addition of animal and vegetable oils, forming emulsions, and a widely favoured lubricant has a composition of 10 gallons water, 3 lb. soap and 3 lb. soluble oil. The use of lubricants containing abrasive substances for the working of copper alloys—similar to the adoption of lime and flour in steel drawing—is not favoured, although the application of " metal polish " to the surface of the metal strip is known to be of assistance in the prevention of fouling; graphite and zinc oxide powder have also been suggested for this purpose.

The " fouling " of the tools, due to building up of metal particles on both the punches and dies, but more particularly on the latter, is an important matter. To a large extent it determines the cost of operations, as it is necessary to stop production when such " fouling " occurs, and to strip down the machine, clean the tools and afterwards reset them again. Metals behave differently in their tendency to give fouling and special treatment of the dies—such as plating with chromium —is occasionally adopted. Of the group of copper alloys, brass is by far the most important for presswork operations and, as it has some of the qualities of a bearing metal, its " fouling " tendencies are generally found to be very low, so that long periods of continuous production can be attained.

It has already been stated that it is difficult to make definite recommendations regarding the most suitable lubricants for the pressworking of copper alloys, since full agreement among the experts has not yet been reached. It may, however, be useful to mention some of the opinions which have been expressed in published articles. Spring[39] divides his suggestions for brass, as given below, into three sections, according to the severity of the forming operations: Mild, Medium and Severe, the last-named involving a considerable amount of ironing. In most cases, the lubricants apply also to copper, although this requires more efficient lubrication than brass.

Mild

1. Soap solution (0·03 to 2 per cent. high titer soap).
2. Fat or oil emulsions with soap emulsifier.
3. Lard-oil blends (10 to 20 per cent. lard oil in mineral oil).

Medium

1. Soap solution. Soap should be high titer (39 to 42 per cent.), fatty acids and free alkali should be less than 0·07 per cent. Solution should be low concentration (0·03 to 1·0 per cent.) and lubricant should contact work at least 30 sec.
2. Fairly rich fat or fatty-oil emulsions with soap emulsifiers. Free fatty acid in the paste base, if diluted with eight parts of water, should be at least 2 per cent.
3. Lard-oil blends (25 to 100 per cent. lard oil in mineral oil). Free fatty-acid content should be 1·5 to 5 per cent. Addition of about 1 per cent. melted tallow, 0·25 per cent. stearic acid to 1 to 2 per cent. soap solution is desirable for medium to severe draws.

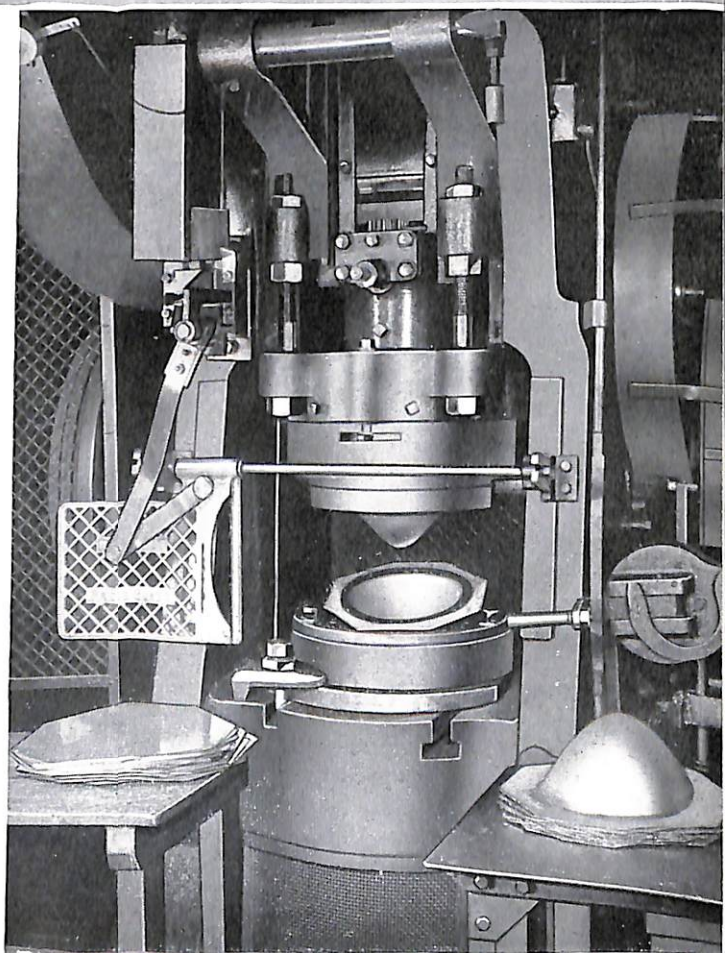
Severe

1. Soap solution of 0·3 to 1 per cent. or one of 1 to 2 per cent., containing 1 to 2 per cent. tallow or 0·25 per cent. stearic acid. Lubricant and work should be in contact longer than with less severe draws.
2. Rich lard-oil blends (75 to 100 per cent.).
3. Dried soap.

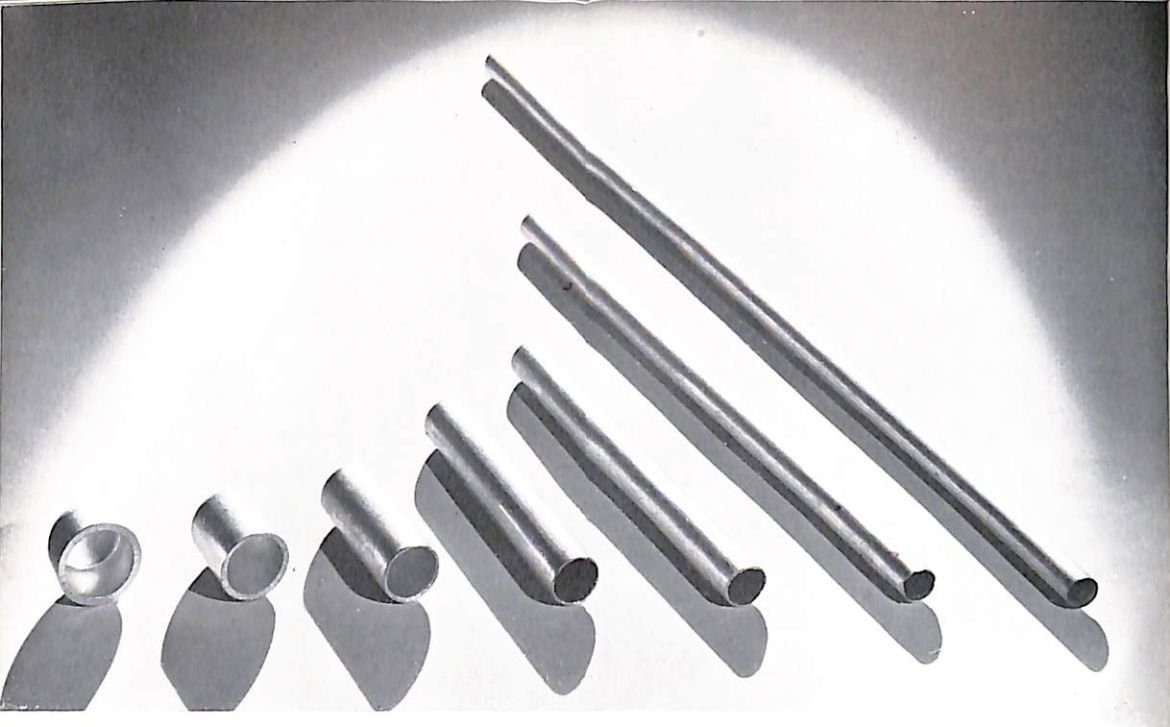
Evans, Silman and Swift[40] refer to tests with brass, covering the conditions of free drawing, drawing with corrective ironing and pure ironing with dies of 10 degrees and 30 degrees angles. The following lubricants were investigated:—

1. Liquids: Mineral oil; Naphthalene tetrachloride; thioether phosphide; hypoid.

Above.
Headlamp body pressing (approx. 8½ ins. dia., 6 ins. deep and 0·030 in. thick), obtained in one draw from brass blank. Polished headlamp body on right.

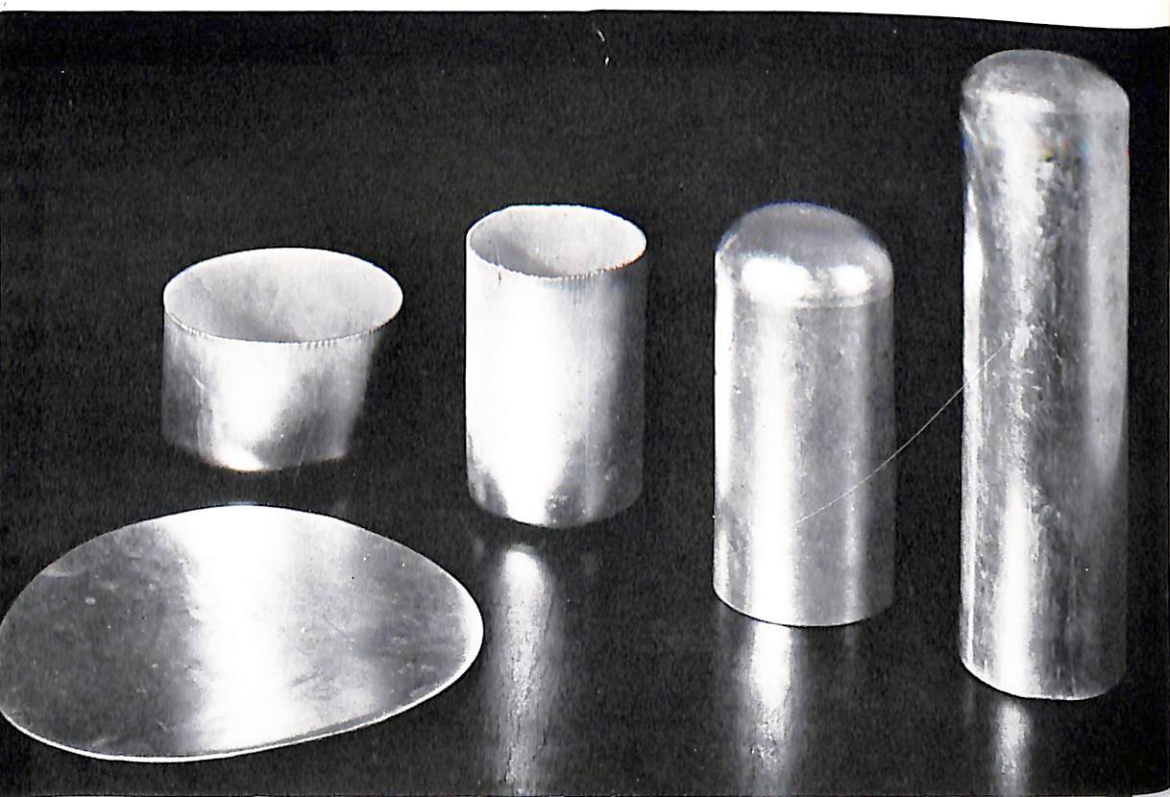


Right.
Press employed for forming headlamp reflectors from octagonal blanks.



Above. Successive " draws " in the fabrication of brass inflator tubes for cycle pumps, during which the metal is reduced from about 0·10 in. to 0·02 in. thickness.

Below. Brass blank and intermediate drawn products in the manufacture of fire extinguisher bodies.



2. Tallow.
3. Soaps: Sodium oleate; chromium oleate; calcium oleate.
4. Kaolin.
5. Graphite: In tallow; dry.

The authors state that, under free and corrective drawing, the pure liquid lubricants showed no significant advantage, with the exception of hypoid, which gave about 7 per cent. reduction of load. The soaps proved rather satisfactory and were, on the whole even better than the graphite lubricants, with load reductions approaching 20 per cent., as compared with 12 per cent. for the graphites. Under the more severe conditions of ironing, the liquid lubricants seem quite useless, giving rise in all cases to an increased ironing load, particularly when mineral oil is used with the small angle die. The tallow and soaps give a load reduction of 5 to 7 per cent., kaolin nearly 10 per cent. and the graphite lubricants about $12\frac{1}{2}$ per cent.

Chisholm[42] makes the general recommendation for the press drawing of non-ferrous metals that mineral oils should be selected varying in viscosity from 43 to 220 Centistokes at 100° F., the choice depending on the gauge of material and severity of draw. The oils should contain the following types of additive, either singly or in various combinations:-

1. Film strength improvers: French chalk; sulphur compounds; chlorinated materials; organic phosphorus compounds.
2. Lubricity improvers: Synthetic esters; fatty oils.

Chisholm explains that high film strength is necessary to avoid seizure and high lubricity reduces the load and power required for drawing. Reference is also made in a general way to the influence of subsequent processing on the choice of lubricant.

Preferred orientation and the formation of ears.

It may sometimes be found that objectionable " ears " occur on the edges of the cups. These are caused by " directional properties " in the sheet or strip, arising from excessive rolling reductions before the final anneal.

REDRAWING OPERATIONS.

Redrawing, in presswork, refers to a variety of processes in which a cup is reduced in diameter and/or thickness by drawing it through a die, and the terms "double and single action redrawing" apply according as a blankholder is or is not used. The oil stove products shown on page 7 are examples of redrawing with no thinning whereas, in the case of the inflator tubes on page 26, the method of working is comparable with that of tube drawing and there is appreciable reduction of metal thickness at every stage. Since there is a natural tendency for the thickness of metal to increase when the diameter of a cup or shell is reduced, some ironing must take place in redrawing to prevent the cylindrical part of the shell from thickening, and rather more ironing is necessary to effect actual thinning. The thickness of the cup is of course governed by the radial clearance between punch and die and when this is restricted for the purpose of ironing, part of the punch load is transmitted directly through the metal at the throat of the die, thus correspondingly relieving the lower cup walls of tension. It is this circumstance which makes possible the drawing of really deep articles, such as cartridge cases and inflator tubes.

It has already been stated that cups of diameter slightly less than half that of the blank diameter may be produced in one operation; this is referred to as a diameter reduction of 50 per cent. In subsequent stages the percentage reductions may also be stated in terms of the diameter reductions, although in cases where thinning takes place it is preferable to express the amount of work by calculation of the reduction of cross-sectional area of the metal at each stage. It is, in fact, desirable to have a knowledge of both the cross-sectional reductions and the reductions of diameters. An essential principle in any sequence of operations is to arrange for decreased reductions to be performed at successive stages, and also to divide the work between reduction of total diameter and reduction of metal thickness. The importance of such a definite distribution of the total work cannot be too strongly stressed, as many production troubles emanate from a failure to appreciate these principles. In fact, as pointed out by Jevons,[3] it is quite frequent to find that greater reductions are attempted in some of the later stages than in the earlier stages. Much useful information can be

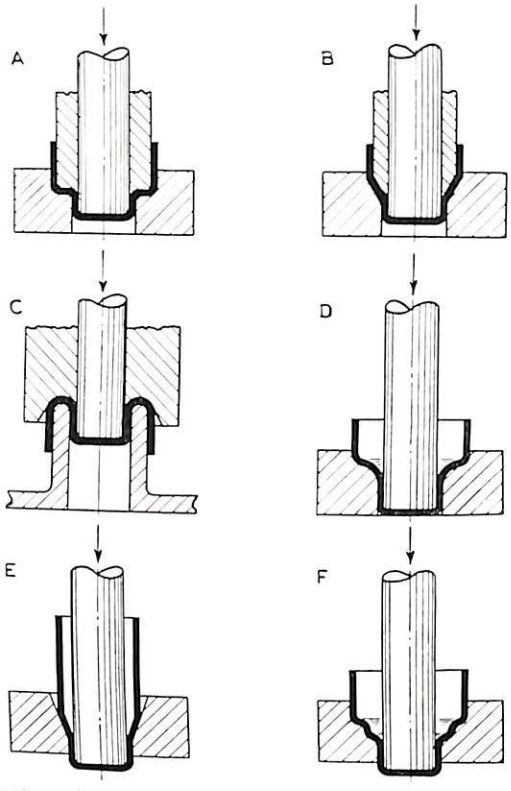
derived from graphs in which the amounts of work performed at each stage are plotted.

The reductions which may be performed vary very much with the particular products; for instance, greater amounts of work may be carried out upon heavy than upon light gauge materials. In single-action redrawing, the reductions (calculated by increase of length of products) which may be adopted are frequently of the order of 30, 25, 16, 13 and 10 per cent. in successive draws; for light gauge products (when the use of double-action tools is generally necessary to prevent buckling), the first redraw may not amount to more than 20 per cent., with correspondingly lesser amounts for the subsequent redraws. Where the redrawing operations involve thinning of the walls, rather than reduction of external diameter at each stage, the reductions (calculated on the changes of cross-sectional area) may range up to and even exceed 50 per cent. For light gauge materials, however, the reductions may possibly not amount to more than 20 per cent., and an instance of light gauge products worked according to this method is provided by the inflator tubes illustrated on page 26.

Methods and machines for redrawing.

In the group of redrawing operations in which only change of external diameters is required, with little or no alteration of the thickness of the metal, a number of essentially different methods are adopted, the principles of which are illustrated on page 30. In A and B the operations are carried out with the aid of blankholders on double-action presses. In method A the metal has to make two right-angled bends and this imposes considerable strain, whereas in B the blank-holding surface makes an angle of approximately 30° with the axis of the punch and die assembly, so that the metal is bent twice through 30° angles, thus easing the operation. The " inside out " or reverse redrawing method, which is favoured by many on account of its simplicity, is shown in sketch C; this method is claimed to be of particular advantage for redrawing rectangular shapes. For methods D, E and F, single-acting machines are used, but these are limited to the redrawing of comparatively thick-walled products, as with thin materials there

is a pronounced tendency for wrinkles to form. It will be apparent that in method F the work is divided between the two shoulders of one die (or it may be divided between two dies in series), so that heavy reductions may be made; in fact, reductions in excess of 35 per cent. have been made by this means.



Redrawing operations showing different methods which may be adopted. A and B—double action redrawing; C—reverse redrawing; D, E and F—single action redrawing.

For the group of redrawing operations in which thinning of the metal is the primary object, single-action machines are almost invariably used, the tools being of the types shown in sketches D and E. The punch is provided with a small central hole in order to make extraction of the products from the punch easier, by avoiding the formation of a vacuum.

Various forms of machines are used for redrawing operations, some of these being in the vertical, and others in horizontal or inclined positions. A noteworthy feature of modern types of machines is the

provision of suitable feeding mechanisms, so that rapid production may be attained.

For the mass production of many small articles such as electric lamp fittings, multi-stage presses are sometimes employed; these incorporate in one unit tools for blanking, cupping, drawing, folding, threading and other operations. The setting up of the tools for these machines is naturally very expensive, and such production methods cannot as a rule be contemplated unless the production of at least 50,000 parts is involved. The machines are generally of the single-acting camshaft type carrying up to as many as eight vertical push-rods to which the punches are fixed. The dies are positioned in line in the horizontal die bolster to correspond with the punches, and the intermediate products are generally transferred along the series of dies by a reciprocating feed mechanism consisting essentially of moving fingers; on the occasions when blanking is effected at the last stage, the feeding may be accomplished by the strip material itself.

One incidental advantage of these multiple-stage machines is that it is frequently possible to spread the total work over a greater number of stages, and hence the operations proceed more smoothly. When operating the more conventional type of single-stage machines there is always the tendency to attempt reductions which are too heavy, so that the metal is worked almost to the limiting extent, leaving little margin of safety. Under such conditions, too, there is more wear on the tools.

MISCELLANEOUS PRESSING OPERATIONS.

Rectangular and other complex shapes.

Rectangular and other shapes involving comparatively sharp corners or flanges such as, for instance, the automobile radiator shell pressing illustrated on page 52, are not generally produced in push-through type machines. Special care is needed in design of the dies and operation of the presses employed, owing to the crowding of the metal at the corners.

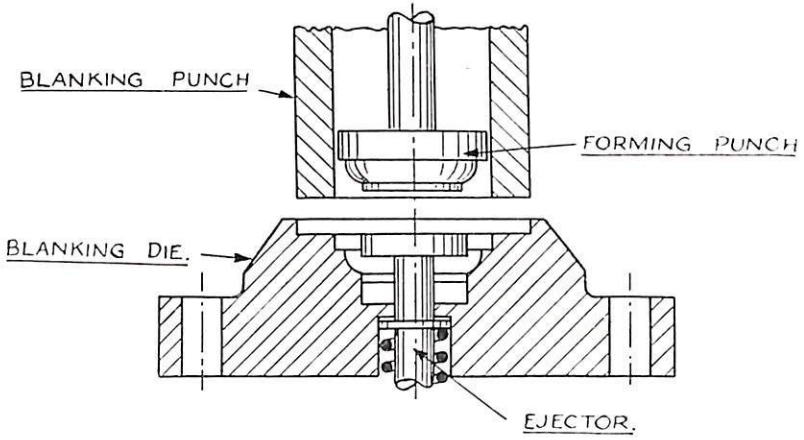
Quite frequently in the production of these types of pressings fracture or bursting occurs at one or other of the corners. This bursting is generally associated with excessive pressure upon the flange in the neighbourhood of the corners, caused primarily by the thickening of the metal; it is, therefore, advisable to relieve at the corners the

surfaces holding the blank in order to facilitate the thickening at these positions and also to prevent excessive wrinkling of improperly held metal at the sides. It is almost impossible, however, to prevent some wrinkling of the metal in the flanged portion of certain difficult pressings, but in most instances this is not of great detriment, provided that the wrinkling does not extend into the walls.

Although it is difficult to give specific recommendations, the depth of draw when making comparatively sharp-cornered pressings should be limited to about six times the corner radius.

Flanged cups and other shapes.

Flanged cups and other shapes may be made either from blanks or from strip on both single- and double-acting presses, the tools being



Tools for production of shaped cups on double-action press.

similar to those used for cupping as outlined previously, with the exception that the dies are generally of the solid bottom type and incorporate a spring-acting ejector mechanism. A sketch of tools for blanking and forming shaped products is given above.

For the production of pressings of the headlamp or reflector types the dies as a rule consist only of a shallow ring, so that the drawn products conform to the shape of the punch. The pressure applied to the blank-holder is generally very great in order to prevent excessive slip, as the process depends to a large extent upon stretching and thinning of the metal; naturally there is a limit to the amount of stretching

which can be sustained and it is necessary to maintain a careful balance between stretching and slipping. Owing to this method of working, a rigid control of the properties of the strip material must be exercised, especially in regard to grain size, which must be kept small; otherwise the surface may acquire an " orange-peel " appearance, with increase in the cost of subsequent polishing. At the same time, however, the strip must be sufficiently ductile to avoid wrinkling and fracture of the products.

Properties of metal for shallow pressings.

Products, the manufacture of which involves comparatively little deformation, can frequently be made from strip or sheet of a temper selected so as to give special advantages. Thus hard and strong, shallow pressings can be made from semi-hard material. A guide to

Right.
Jug, mugs and tray pressed and spun from copper sheet.

the hardness ranges of brass strip and sheet for certain applications is given on page 60. For other materials also, depending on the product, certain hardness ranges may be found to be the most suitable.

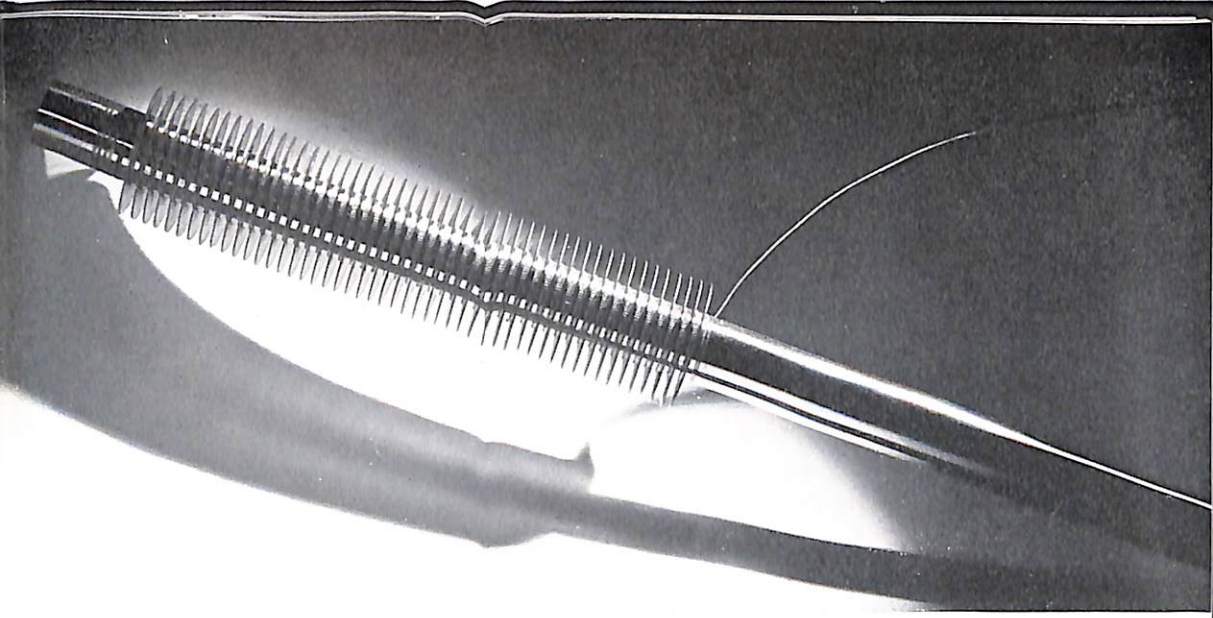
EXPANDING AND CONTRACTING OPERATIONS.

Quite frequently it is necessary to perform expanding, contracting, rimming and many other similar operations upon drawn products. The expansion or contraction which may be effected largely depends upon the ductility of the material and in the case of the ductile copper alloys in the annealed condition, expansions of 30 per cent. may be obtained in one operation.

It is difficult to give an adequate description of expanding methods, as these depend so much upon the products. Hydraulic expansion within closed split dies is the most convenient method in certain circumstances, although this method has limitations.

For bulges and small rims in thin-walled pressings, a very common method involves the employment of " cylinder " rubber expansion pieces attached to the ends of steel punches. On other occasions, the punch may be in two sections separated by a rubber cylinder, the expansion being effected by the punch striking the bottom of the article. In the case of tubular products without base, two punches with rubber heads may be brought together from opposite directions so that the rubber end pieces are expanded. Whenever such rubber expansion pieces are used, it is necessary to surround the article completely with split dies which enable the finished article to be extracted. This method of expansion is chiefly confined to small production quantities, as the rubber must be replaced at frequent intervals owing to comparatively rapid wear. Consequently, steel expansion pieces, constructed in segments and operated by springs, are frequently used when the number of products required is large. The only disadvantage of such segmented expansion pieces is that slight flats on the surface of the articles are unavoidable.

In reducing operations, such as necking, rimming, tapering, nosing and closing, the pressings are inverted so that the open ends enter the die first, with the punch pushing externally on the base. In rimming,



Copper strip (0·015 in. thick) in tubular heat-exchanger elements. The strip is bent on edge and knurled into a spiral groove on the copper tube.

the whole of the cylindrical section is reduced in diameter except for the base. Reducing operations of a severe nature occur in the manufacture of numerous articles, such as pressure cylinders, fire extinguisher bodies and cartridge cases. The metal must initially be in the annealed condition and quite clearly there is a limit to the amount of closing-in which may be effected in one operation; reductions of 5 to 15 per cent, in diameter can perhaps be regarded as representative of current practice. Bulging and reducing operations may also be performed by spinning.

Rimming the heads or bases of heavy-gauge cartridge cases is normally done by bumping. Since much plastic deformation is involved, it is best to select materials of high ductility.

Small springs sheared and bent up from phosphor bronze and nickel silver strip.

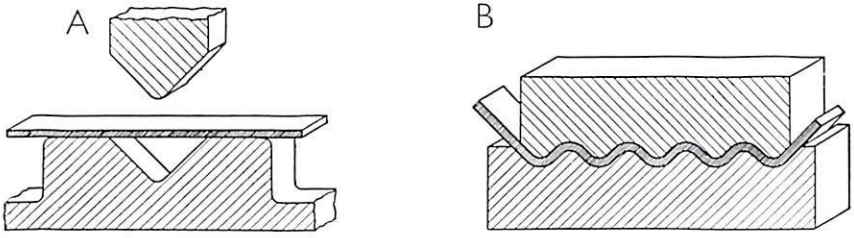
BENDING AND FOLDING OPERATIONS.

In this group of operations, the principal technical point to be observed is in connection with the "temper" or hardness of the strip and sheet material, the properties of which should be chosen so that the required bending or folding operations can be performed easily without production of cracks or splits.

The principles are essentially of a simple nature, yet the machines employed for carrying out bending and straight-line folding operations in the most economical manner are often very complicated and extremely ingenious. As examples of bent products, illustrations are given above of small springs and on page 53 of crimped strip required for radiator construction; there are numerous other instances where other types of folding and bending operations are involved. Where long lengths of a section are required, then drawing through a suitably designed die by means of a draw-bench is often the most convenient and economical method, and is adopted, for instance, in the production of a large number of shaped sections for architectural and other purposes. When very large quantities of a given section are required, rolling methods may be adopted, although the provision of specially shaped grooved rolls is a costly matter, and hence this method is limited in application. The question of whether a given section can be produced more economically by extrusion from a solid billet, or by folding

rolled strip by either bench drawing or rolling methods, largely depends upon the dimensions, as these production methods have natural economic limitations. Where wall dimensions of less than about 0·060 in. are involved, it is generally considered preferable to produce the required section from strip.

For small bent components such as springs, brackets, picture hooks, hinge parts, etc., the usual method of production is by means of power or hand presses, fitted with tools suitable for the particular bending operations. Fig. A below shows the usual arrangement for obtain-



Tools for strip bending processes.

ing simple bends, from which it will be seen that the only work involved is in local bending of the strip material. The effects of " spring-back " are nullified by bending the workpiece to a smaller angle than wanted, the exact determination of this angle being a matter of experiment. In Fig. B the tool arrangements for effecting several bends or corrugations are illustrated, and in this case there is also stretching of the strip material.

In springs and other products which are formed from hard rolled or drawn strip material, the operations and products should be so designed that the most severe bends are at right-angles to the direction in which the strip has been rolled or drawn, because work-hardened materials are able to withstand more severe bends across the " grain " than with it. The radius of the bends should be made as generous as possible in order further to reduce the risk of surface cracks or splits. Consideration of the relationship of the thickness, hardness and bending properties of brasses, phosphor bronzes and nickel silvers has been made by Straw, Helfrick and Fischrupp[74] and G. R. Gohn.[75] The recommendations relating to minimum radii for 90° bends given in these papers, and other useful information, are contained in C.D.A. Publication No. 39, " Copper and Copper Alloy Springs."

COINING OPERATIONS.

Coining, as a method of fabrication, is not extensively employed and applications are largely confined to coins, tokens, badges, medals, keys, identification and trade discs and plates of comparatively small size. However, when the volume of work justifies the outlay of special machines and dies, coining methods may advantageously be adopted for the manufacture of many other components.

Coining is essentially an operation which requires metal to flow under pressure while cold and this is generally effected in enclosed dies. On this account, considerable attention must be paid to the gauge of the strip and blanks, in order to safeguard against possible damage to the dies or machines by the development of excessively high pressures due to the volume of metal being too great.

The pressure required is largely determined by the depth of coining and the ductility of the metal and it is to some extent increased by higher speeds of working. Quite frequently pressures of more than 100 tons/sq. in. are needed to produce sufficiently sharp impressions, but presses capable of exerting considerably greater pressures are generally employed in order to obtain a sufficient working margin. Obviously the permissible size of coined products is limited by the pressure capacity of the press.

For the production of coins, blanks are first punched from hard-rolled strip and these are " rimmed " by rolling the edges and are subsequently annealed and cleaned. They are then fed to the minting press by ingenious automatic devices and receive the desired impressions by upper and lower dies.

Drop stamping of cold metal, having the advantage of cheapness, is sometimes adopted for the production of certain coined components, provided that the moving die can be guided sufficiently accurately to restrict sideways movement within the desired limits. By this process the impressions are obtained by impact, as against more gradual pressure applied in normal coining methods. Embossing, which is a somewhat similar type of working process, involves the forming of designs on sheet or strip metal without appreciable change of thickness of the latter, the process being effected by means of male and female dies.

Some typical coins, tokens, key blanks, etc., obtained by coining and cold stamping processes.

FORMING BY FLEXIBLE TOOLS.

An interesting development in the light metal industry is the Guerin process,[57, 58] in which metal sheet is pressed between a single die and a flat, thick pad of resilient material such as rubber. The latter is confined within a holder made from steel and attached to the press slide. The pad acts like a fluid under pressure, applying force to the metal uniformly in all directions and shaping it in conformity with the die. Sheet metal under about 19 S.W.G. can also be cut by this method. It is claimed that tooling costs are exceedingly low, that accurate formation of irregular shapes is simple and that several large or numerous small articles can be made simultaneously from a single sheet of metal. In the case of the " Marform " process[60, 61, 62] the blank is placed between a rubber pad and a pressure plate. A steel punch pushes the blank into the rubber, enabling deep cups to be formed. There seems to be no reason why these methods could not be applied to copper and copper alloys.

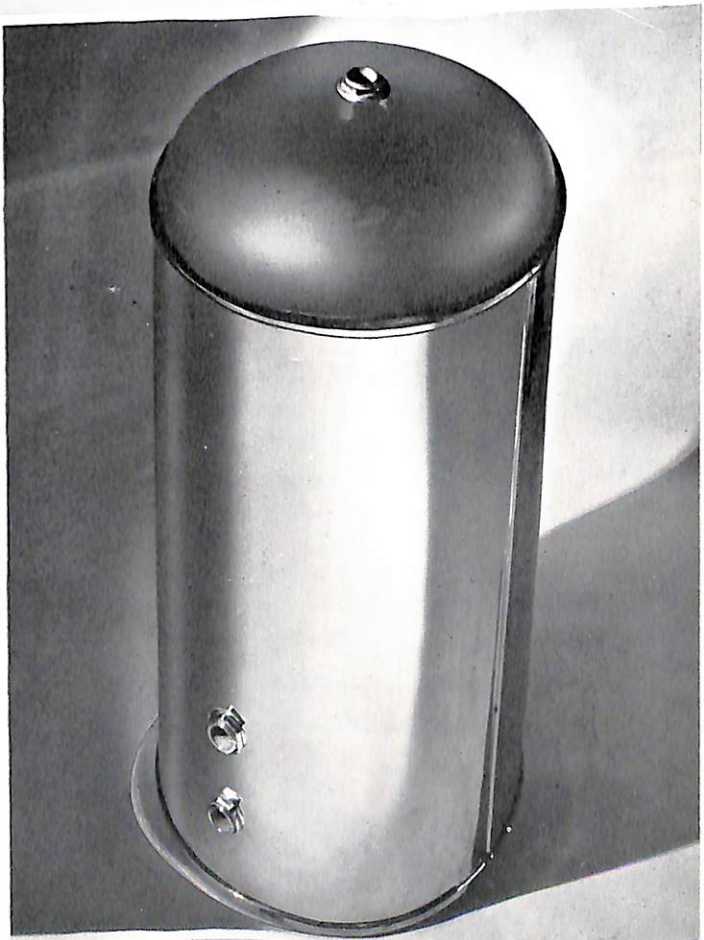
SPINNING.

Spinning is a process by means of which hollow shapes are obtained by the application of pressure to rapidly revolving blanks, so causing the latter to assume some other desired shape. Various examples of spun products are shown on page 41, and the scope of the process will be apparent from these illustrations. Instead of commencing with blanks, spinning may frequently be employed more economically in conjunction with pressing and other operations, while the process may also be applied for edge curling, beading and seaming.

As the equipment required for spinning is very cheap in comparison with that required for pressing, the process lends itself very favourably to the manufacture of small quantities, even though it is relatively slow, while for certain complex articles of re-entrant shape spinning is the only practicable method of fabrication. The equipment necessary consists of a lathe, in which the blanks or other shapes are held between a chuck and a tail plate, and of the forming tools, which are usually simple rods with rounded ends. For external spinning the chuck almost invariably has attached to it a wood or metal " former," corresponding to the internal shape of the finished product, and against which the metal blank or other shape is spun; such " formers " may be of solid or segmented construction as dictated by the shape of the products. Where spinning is carried out from the inside, the " former " is often a shaped

Above.
Group of copper and brass spinnings; the two large spinnings are of 12ins. diameter.

Right.
Hot water storage cylinder made from copper sheet; the top and bottom are pressings or spinnings, and the body is bent to the desired shape and the folded seam brazed.



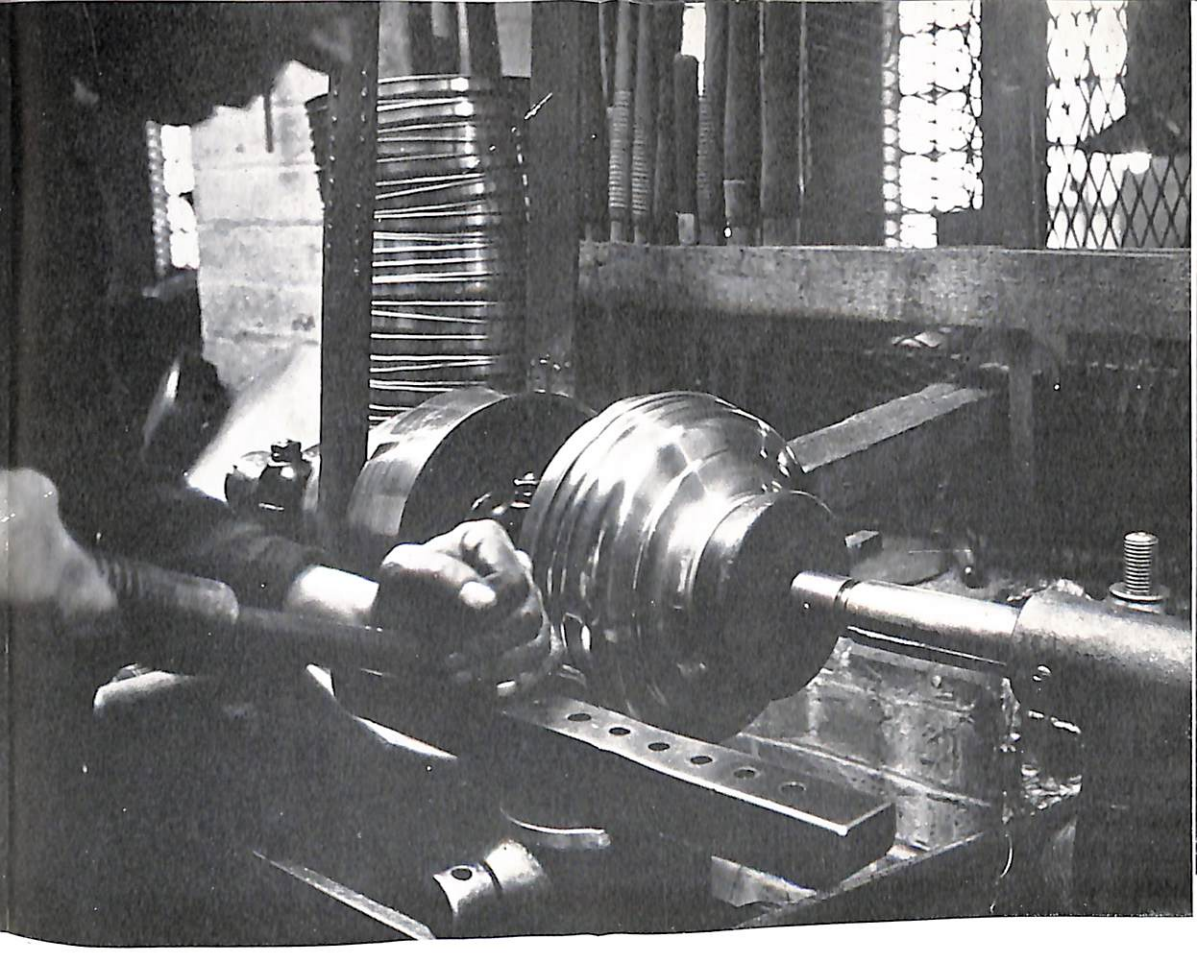
roller turning freely upon an independent spindle. An internal tool performs the necessary deformation, by pressing the metal outwards against the roller.

A great deal of skill and experience is required for spinning and the choice of the forming tool is a matter of importance. The tools are of various shapes and are of considerable length, so as to provide the necessary leverage and control during use; ready means for the movement of the position of the fulcrum pins must be provided on the lathe rest, as it is necessary to change the position of these during working of any one article. Some idea of the process and plant may be obtained by reference to the photograph on page 43, which shows the forming tool in position and the holes in the lathe rest for the movable fulcrum pin. The left hand of the operator steadies the tool against the pin.

If intermediate annealing becomes necessary, this should be followed by pickling to remove all traces of oxide. Adequate lubrication is essential. Thus, for small work, tallow or beeswax is recommended or lard-oil mixed with white lead or petroleum jelly; for larger diameters, ordinary washing or yellow soap is suitable.

The thicker and harder the metal, and the larger the diameter of the job, the slower should be the spinning speed. The following table, which is based on American practice,[54] shows that there is a tendency to employ rather high speeds.

Metal	Thickness (in.)	Diameter (ins.)	Speed (r.p.m.)
Copper	·008	$\frac{3}{4}$	2,400
	·015	5	1,225
	·040	9	1,000
	·062	14	575
Brass	·015	2	1,225
	·032	7	1,000
	·040	8	575
	·050	12	525
	·093	24	450
	·125	36	325
	·187	72	242



A typical spinning operation.

Normally the thickness of blanks to be spun varies between 0·022 in. and 0·128 in. but thicker sections of soft copper have been spun economically. Diameters may vary between $\frac{1}{2}$ in. and over 6 ft., depending on the swing of the lathe. The tolerance on the diameter is frequently about $\pm \frac{1}{64}$ in. and sometimes less, but a tolerance of $\pm \frac{1}{32}$ in. is rather more economical. Greater rigidity is achieved when beaded edges or flanged surfaces are incorporated in the design of parts which are to be spun.

The standard products of the spinning trade are ornamental and decorative copper and brassware, cooking utensils, musical instruments and components needed for plumbing and chemical plant.

While almost any of the ductile copper alloys can be used for spinning operations, copper itself is of particular importance owing to its low

work-hardening rate and the consequent ease with which it may be worked. Of the brasses, 70-30 possesses the highest ductility and is the most common grade for spinning. The golden-coloured gilding metals, the nickel silvers and other copper alloys are also employed, sometimes on account of their colour.

OTHER METAL WORKING OPERATIONS.

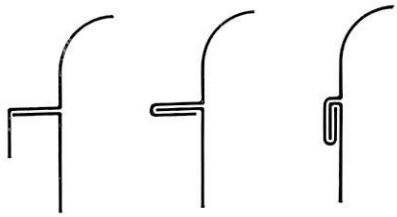
So far, consideration has only been given in this book to metal working processes which are carried out by repetition methods. There are, however, many instances in which individual treatment is necessary, so that fabrication by manual methods must be adopted; this is particularly necessary in the manufacture of comparatively large plant required for special purposes, such as for the chemical industry. The material mostly employed is copper and this is worked in the hot or cold states, depending largely upon the dimensions and amount of deformation involved; brass and other copper alloys are also employed, but owing to their greater strength they cannot be hand-worked with such ease. An outline of the procedure adopted in the working or fashioning of copper by hand methods has been given in C.D.A. Publication No. 23, "Copper in Chemical Plant," so that this subject will not receive detailed attention in the present book.

JOINING.

Although mechanical and other joining processes do not fall strictly within the scope of metal working, yet they are so associated with actual fabricating processes carried out upon strip and sheet materials that they will be briefly considered. The welding, brazing and soldering of copper and copper alloys have been described in C.D.A. Publication No. 47, to which reference should be made for further details.

Seaming. Of mechanical joining methods, that of seaming is the most important for most light-gauge products obtained by pressing and other forming processes. The most usual method for making seams upon round articles is by spinning-over flanges, as adopted, for instance, in the copper floats for ball valves (see photograph on page 41). The principles involved in forming seams by this method will be apparent from the figures opposite, which show three different stages. On

irregularly shaped articles, it is not possible to make seams by spinning, and where large quantities are involved special machines may be installed for the purpose; in other instances it is necessary to form and close the flanges more or less by hand-beating methods. It will be appreciated that a fairly severe amount of bending is involved in the formation of seams, and hence the temper of the original material must be such that the necessary amount of bending can be accomplished with safety; where convenient, or necessary, local annealing may be carried out prior to seaming.



Stages in the formation of seams.

Of more importance and wider application than the foregoing and other mechanical joining methods are soldering, brazing and welding processes, which may be performed easily upon all copper alloys.

Soft soldering is done in several ways, depending on the number and size of the components and the types of joint. Dipping the work after cleaning and fluxing, in a bath of molten solder is one of the most important processes and is applied, for instance, in radiator manufacture. The other principal methods involve heating the joint area by soldering bit, torch, furnace, induction, or electric resistance, with the solder either preplaced or applied to the heated work. The composition of the most popular soft solders is specified in British Standard 219. Fluxes for soldering are broadly divided into the chlorides (zinc chloride, ammonium chloride and hydrochloric acid) and the activated resins. The removal of the corrosive chloride fluxes after soldering is generally desirable and, where this is difficult, resin type fluxes are to be preferred. Special fluxes are required for beryllium copper.

Brazing (including silver soldering) is carried out at much higher temperatures than soft soldering though the joint design is similar. The compositions and melting ranges of the various filler alloys are

given in British Standard 1845. The joint area may be heated by torch, furnace, dipping in a bath, induction or electric resistance and recommendations as to choice of process and filler alloy are contained in British Standard 1723. The joints suitable for brazing, as for soft soldering, are of the capillary lap type, but brazed joints are rather stronger.

Bronze welding by gas is the subject of British Standard 1724. In this process, the joint preparation and technique resemble those of gas welding but the filler alloys are nickel brasses or silicon brasses. Bronze welding is suitable for copper and other, mainly ferrous, metals but is hardly applicable to any of the copper alloys except cupro-nickel.

Welding processes, such as gas, arc and resistance welding, result in the fusion of the parent metal. In gas and arc welding, the joints are frequently filled with additional metal of a composition similar to that of the parts to be joined. Such " autogenous " welds are to be preferred if dissimilar metal corrosion in the presence of certain liquids must be avoided. Resistance welding processes, such as spot and seam welding, are particularly suitable for the joining of light gauge sheet or strip products, whereas in gas and arc welding the danger of "burning through " thin material is serious. Copper itself, on account of its high conductivity, can be resistance welded only in very thin sections with plant of large current capacity. The strength of most welded joints in copper and copper alloys may be enhanced by cold working such as hammering.

Tough pitch or oxygen-bearing copper is susceptible to " gassing " (see page 47) when welded, bronze welded, or brazed in a reducing flame, or when furnace brazed in a reducing atmosphere. Special steps must therefore be taken to avoid this. The deoxidised and oxygen-free grades of copper, and the copper alloys, are immune from this type of failure.

In soft soldering, the temperatures reached and the periods for which the metal parts are exposed to the heat are such that little or no annealing of cold-worked material takes place. In brazing, bronze welding, and welding, annealing cannot be avoided, though in the case of induction brazing, resistance brazing and resistance welding, the annealed zone is extremely small and localised near the joints.

ANNEALING.

Annealing is a necessary stage in the manufacture of many components from copper alloy strip and sheet, particularly when several "draws" are involved. It is advisable for the annealing operations to be carried out under accurately controlled conditions, as improper treatment may result in various defects.

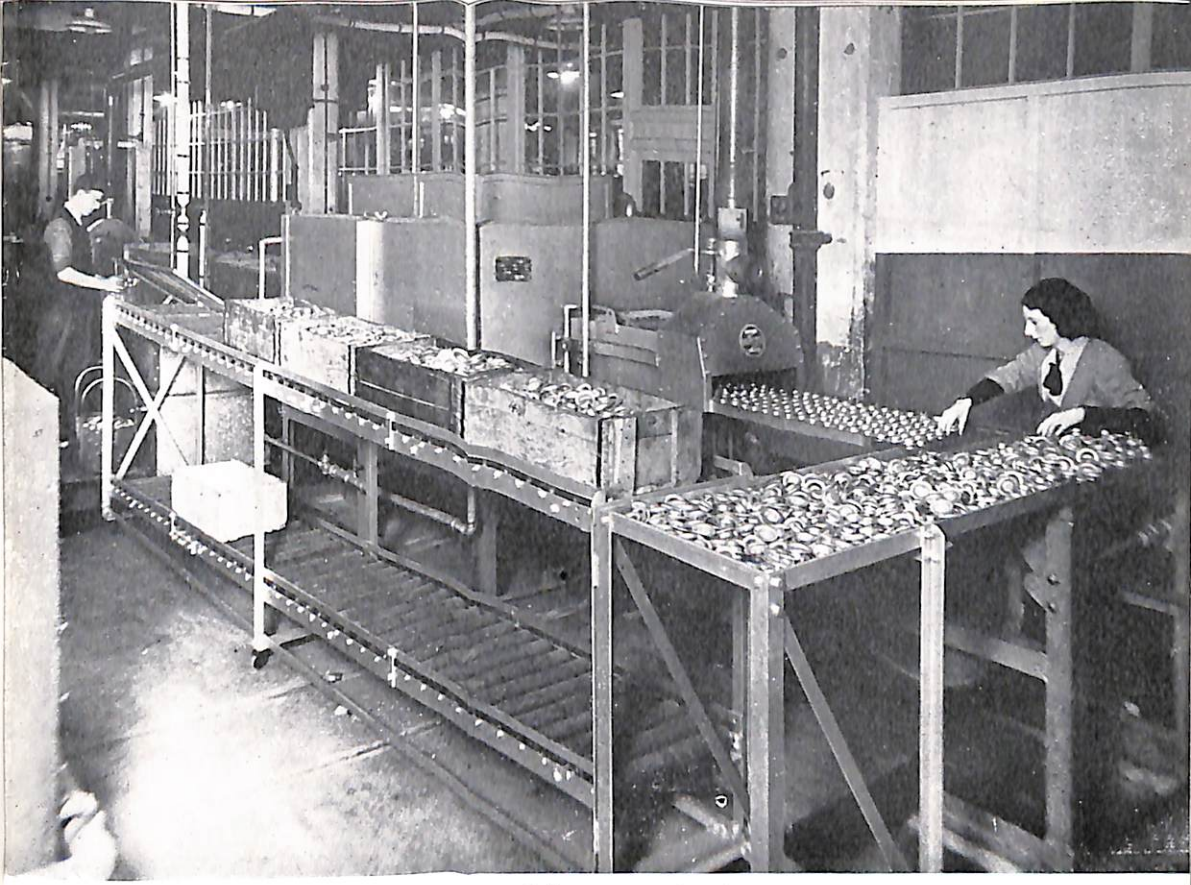
The annealing of copper has been considered in some detail on pp. 34-37 of C.D.A. Publication No. 12, "Copper Data." It is not often that annealing operations are essential during the working of copper strip and sheet, at least by the methods principally considered in this book, owing to its extremely low work-hardening rate. If, however, the annealing of small components is required, it is usual to employ one of the many forms of "bright annealing" furnaces, to prevent the oxidation and scaling which occur when annealing in ordinary atmospheres, with a consequent loss of "surface finish." While pure copper can be annealed at temperatures as low as 200° C., it is usual for very much higher temperatures to be employed, as some commercial coppers—such as arsenical copper—do not soften until the temperature somewhat exceeds 300° C. For the annealing of heavy charges a temperature of 500° C., or even 600° C., is quite frequently employed. The time of annealing varies very much with the furnace and the charge but is generally about half an hour to one hour.

Tough pitch copper, which contains cuprous oxide, must on no account be annealed in a reducing atmosphere or serious embrittlement will result. Hydrogen can penetrate into the copper with ease, where it reacts with the cuprous oxide to form steam at sufficient pressure to disrupt the metal. This phenomenon is commonly known as "gassing." Burnt ammonia with about 2 per cent. of hydrogen and partially burnt fuel gas containing 2–3 per cent. of hydrogen and carbon monoxide are considered suitable reducing atmospheres, provided that the annealing temperature does not exceed 400° C. If tough pitch copper is to be annealed at higher temperatures, only traces of hydrogen are permissible in these atmospheres. On the other hand, deoxidised copper and, of course, copper alloys are not susceptible to gassing at any temperature. Copper is very sensitive to staining by hydrogen sulphide and, if staining is to be completely avoided, the permissible

sulphur content should not exceed 0·3 grain per 100 cu. ft. of atmosphere gas. Attention must also be paid to staining which may possibly be caused by the lubricants on sheet metal products. Mineral oils often have a relatively high sulphur content, but oils containing up to 0·1 per cent. are available and should be used. Heavy tallows, on the other hand, may leave troublesome carbon deposits, if not removed before annealing.[70]

When annealing commercial brasses it is necessary to exercise very accurate control of time and temperature as the alloys, in contrast to copper, are liable to rapid grain growth. The conditions of annealing are varied in practice with the composition, purity, and mechanical properties of the brasses, while the type of furnace employed and the relative weight and distribution of the charge are further factors which exert an influence upon the time and temperature of annealing. However, for brasses of the compositions normally encountered the annealing temperature lies generally between 500° C. and 600° C. The former temperature results in a minimum anneal while the latter gives a full anneal, the resultant grain size generally being of the order of 0·05–0·06 mm. However, there are so many factors which have an influence upon this—including original grain size and amount of cold working—that it is not possible to give exact figures. The necessity for exercising technical supervision when annealing brasses cannot be too strongly stressed, as insufficient annealing may give rise to fracture of products in subsequent drawing stages, while excessive annealing may also interfere with working and will in any case give roughened or " orange peel " surfaces, which require additional effort in polishing.

It is not easy to find suitable protective atmospheres for the annealing of brasses containing more than about 15 per cent. of zinc. In a strongly oxidising atmosphere, there is considerable zinc oxide formation and in a fully reducing atmosphere, the absence of a superficial oxide film permits loss of zinc by volatilisation, causing a roughening of the surface and a change in colour. The effect is negligible if the heating time is very short at a high temperature (flash annealing), or if the temperature is kept very low (around 450° C.) for a longer period, but in neither case may bulky articles of heavy gauge metal be fully softened. In " clean annealing " of brass, the oxidation is confined



Continuous type of electric annealing furnace.

to a thin film of zinc oxide by using mildly reducing atmospheres, including those in controlled direct gas-fired furnaces. (Even traces of water vapour in a reducing atmosphere at elevated temperatures are capable of oxidising zinc.) Since the oxide film may readily be removed by flash pickling in dilute acid, clean annealing is probably the best method for brass.

The annealing of nickel silvers is usually carried out at temperatures between 700° C. and 800° C., depending on the nickel content.[76] It is less likely to lead to discoloration, partly because of their relatively low zinc content, but degreasing before heat treatment is usually essential to prevent lubricant staining. Aluminium bronze, silicon bronze, chromium copper and beryllium copper can be truly bright annealed only in very pure hydrogen or in mixtures of nitrogen and hydrogen such as cracked ammonia, since all the addition elements in the alloys have great affinity for oxygen. However, the finish resulting from a reducing atmosphere, such as partially burnt coal gas, is acceptable for many purposes.[70]

Annealing is generally carried out either in gas-fired or in electric

furnaces. In addition to the conventional batch-type furnaces, forced air circulation furnaces may be mentioned, which are claimed to ensure accurate grain size control. When output requirements are high, small copper alloy products may also be annealed in continuous furnaces (see photographs on pages 49 and 51), or in continuous rotary drum furnaces.

In the production of components which necessitate large amounts of local deformation, as for example the tapering or necking of shells and cartridge cases, it is necessary to resort to local annealing of the products. Frequently such annealing is carried out by means of open gas burners, the products being passed through the flames for a short period only; or electric induction heating may be used. This practice often has the effect of leaving red stains after ordinary pickling, but these can be removed by " bright dipping " as described on page 54.

More detailed information on the annealing of copper and copper alloys, and on suitable equipment, will be found in the papers listed in the Bibliography.[70-73]

Stress Relief Heat Treatment.

In products made from certain copper alloys, the presence of internal stresses after cold working may give rise to subsequent cracking in service. Such " season cracking " is especially encountered in articles made from brasses containing less than 80 per cent. copper, and is a form of corrosive attack, the failures being especially encountered in atmospheres contaminated with traces of ammonia. Products which are not under internal stresses, such as those which are fully annealed, exhibit no tendency to " season crack." Copper itself, even in the cold-worked condition, is not normally liable to this form of failure.

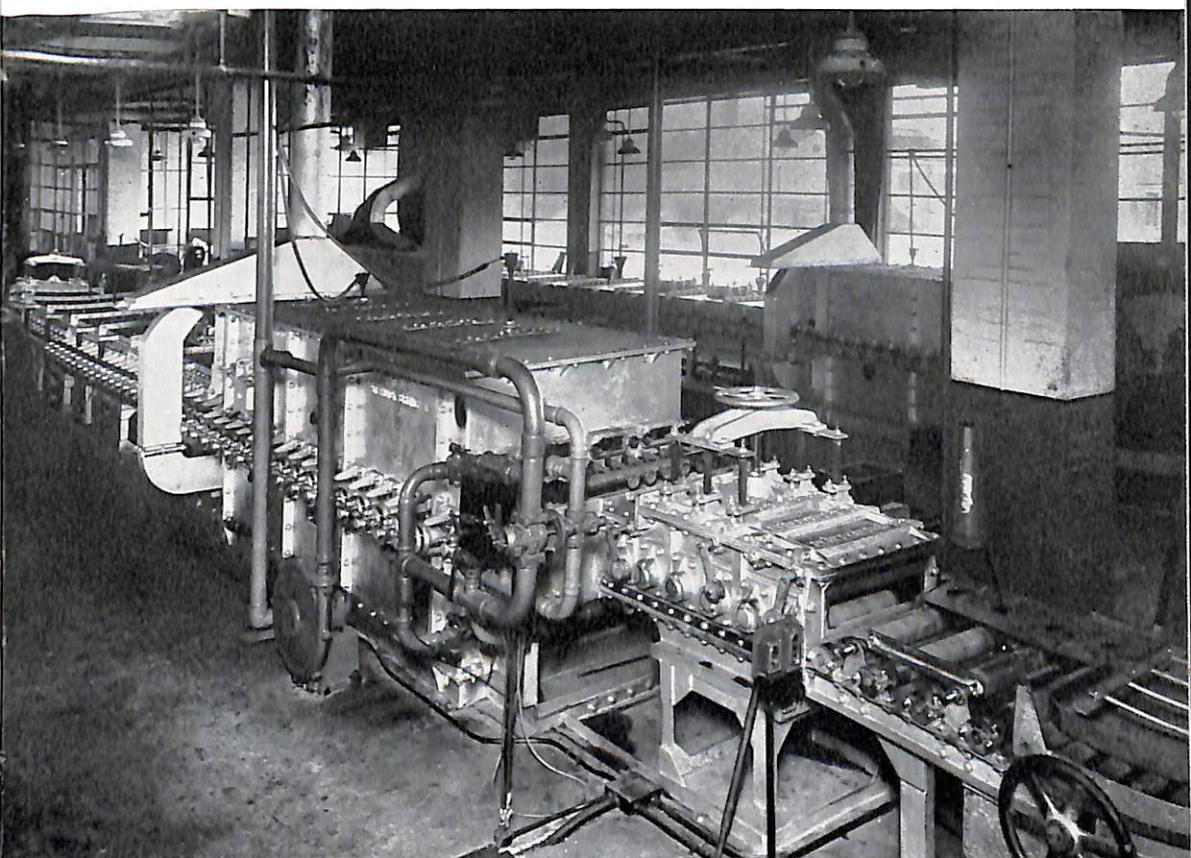
To safeguard cold-worked brass and other copper alloy products against " season cracking," a low temperature heat treatment is recommended. For brasses the treatment usually involves heating at 250° C.-275° C. for half to one hour and does not result in softening of the work-hardened material, though it relieves the internal stresses. The corresponding temperature range for nickel silver is from 275° C. to 325° C. In certain circumstances, however, it is possible to arrange the working or finishing operations so that internal stresses of a high order are avoided and hence heat treatment operations are not necessary.

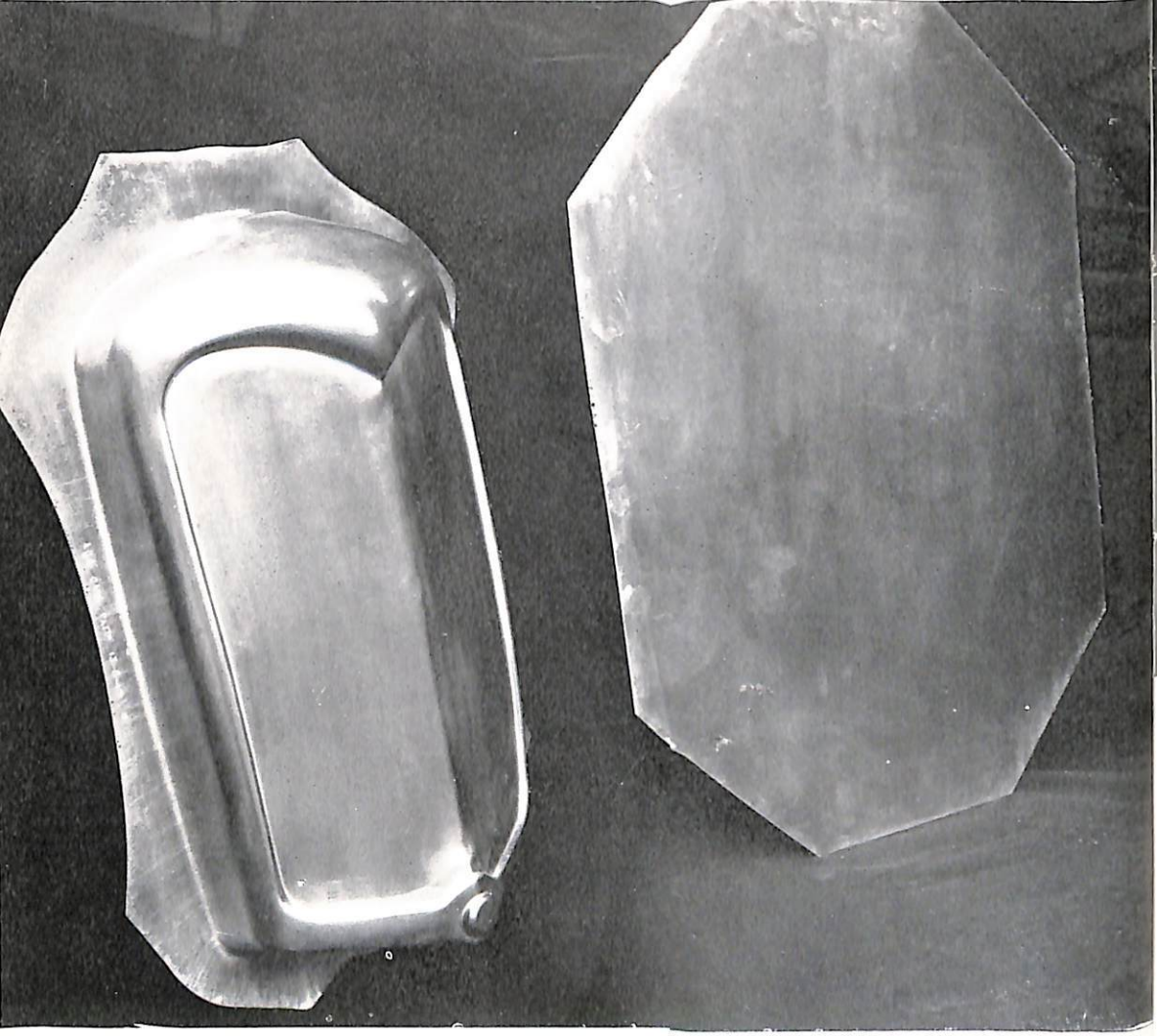
The presence of internal stresses, and hence the liability to "season cracking," can be detected very easily by means of a simple and rapid test in a mercury salt solution. Samples for the test should be clean and should first have all grease and oil removed by degreasing and then be dipped in a solution of 50 per cent. distilled water and 50 per cent. concentrated nitric acid (sp. gr. 1.42) for a period not exceeding 30 seconds. They should then be well rinsed in cold water and immediately immersed completely in a 1 per cent. by weight solution at room temperature of mercurous nitrate in distilled water to which 1 ml. of concentrated nitric acid (sp. gr. 1.42) has been added for each 100 ml. of solution. The samples remain in the solution for thirty minutes and are then removed, rinsed well in cold water and carefully wiped, after which they should not exhibit any signs of cracking. Test samples should not be marked for identification by stamping.

Pickling.

The pickling of copper alloys, so as to remove scale, etc., formed during annealing, is usually performed in a dilute sulphuric acid solution, the composition of which need not be very accurately controlled.

Gas-fired continuous bright annealing furnace for copper alloy pressings.



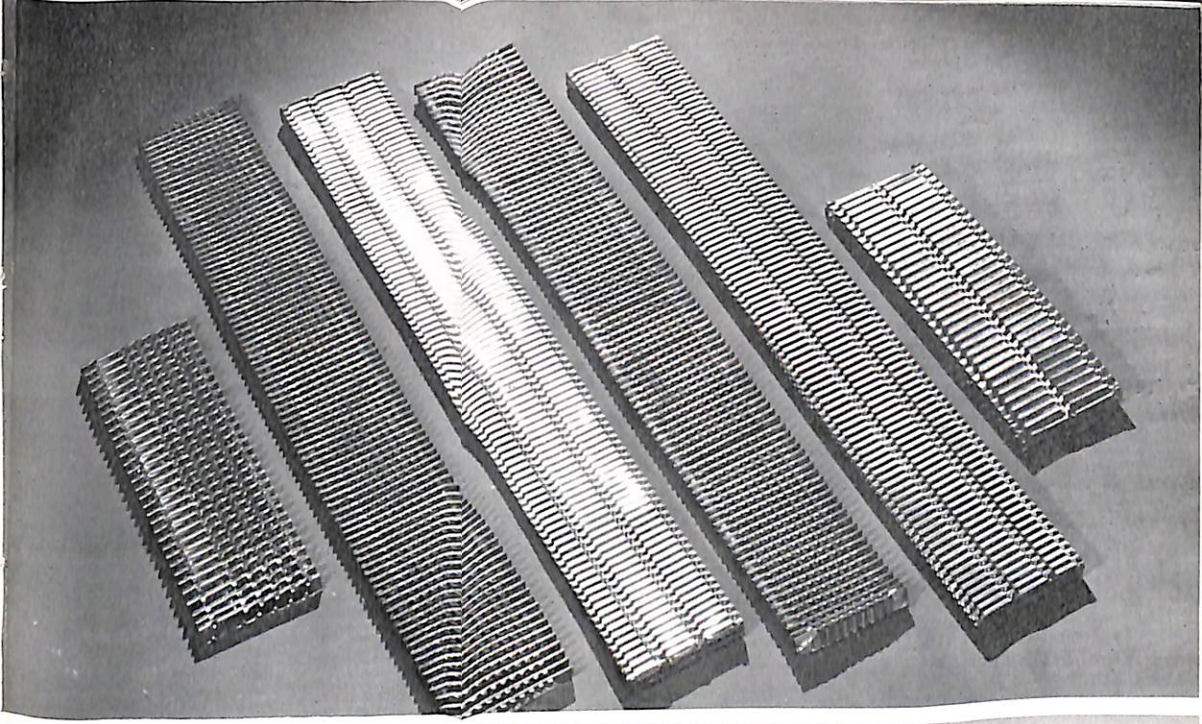


Above.

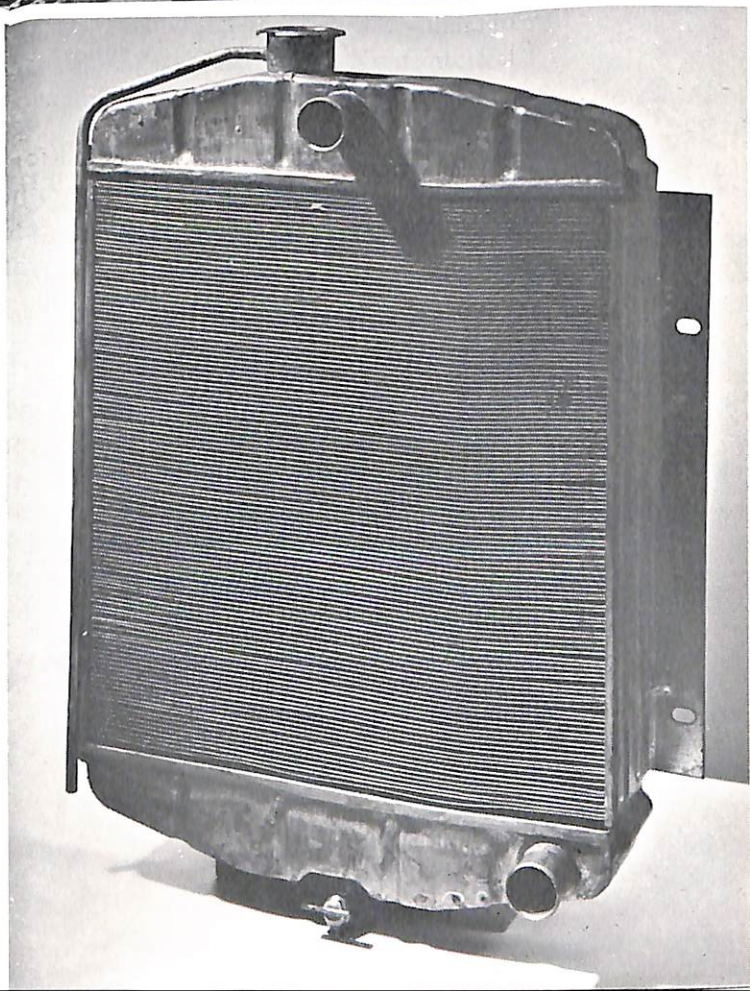
Radiator shell pressed in one operation from brass sheet blank, 0·036 in. thick and 3 ft. high.

Right.

Wheel disc pressing $12\frac{1}{4}$ ins. diameter in brass 0·036 in. thick from $14\frac{1}{2}$ ins. square blank.



Above.
Crimped copper foil (0.004 in. thick), for water and air ways of radiators.



Right.
Automobile radiator core of the fin and tube type. The fins are perforated and crimped copper foil, and the tubes are formed from brass foil. The top and bottom tanks and side pieces, the overflow tube and other fittings are also copper alloys. (*Ford Motor Co., Ltd.*)

A suitable pickling solution may be made up with ½ gall. to 1 gall. of "brown" vitriol in 10 gall. of water.* A more vigorous attack may be obtained by the addition of nitric acid or of chromic acid, or a bichromate salt in amounts of about 5 per cent.

Bright Dipping.

For the "bright dipping" of finished products made from copper alloy strip and sheet, much more vigorous solutions are necessary. The most frequently employed bright dips are made up with sulphuric and nitric acids; one such dip possesses an approximate composition of 30 per cent. nitric acid (sp. gr. 1.42), 30 per cent. sulphuric acid (sp. gr. 1.84) and 40 per cent. water by volume. Commercial acids of lower specific gravities may be used in approximately proportionate ratios, but the actual composition of a bright dip should be varied according to individual conditions. The solutions should be used cold for obtaining the best results, while the addition of a little common salt is often stated to be an advantage. The solutions need care in preparation and should be used only in earthenware vessels.

The products should be immersed for only half a minute or so in the acid mixture and should then be washed thoroughly in clean water and subsequently dried. A bright golden colour may be obtained on brass alloys by this means. If a more yellow colour is required, this may be obtained with solutions of dilute sulphuric acid and either chromic acid or a bichromate addition. One such dip possesses an approximate composition of ½ gall. to 1 gall. of "brown" vitriol and 5 lb. to 10 lb. of potassium bichromate in 10 gall. of water; this should be used cold and the products immersed for periods up to several minutes.

* The vitriol should of course be added *slowly* to the water, with constant stirring.

Section 3.

MECHANICAL PROPERTIES AND COMPOSITION OF COPPER AND COPPER ALLOY STRIP AND SHEET.

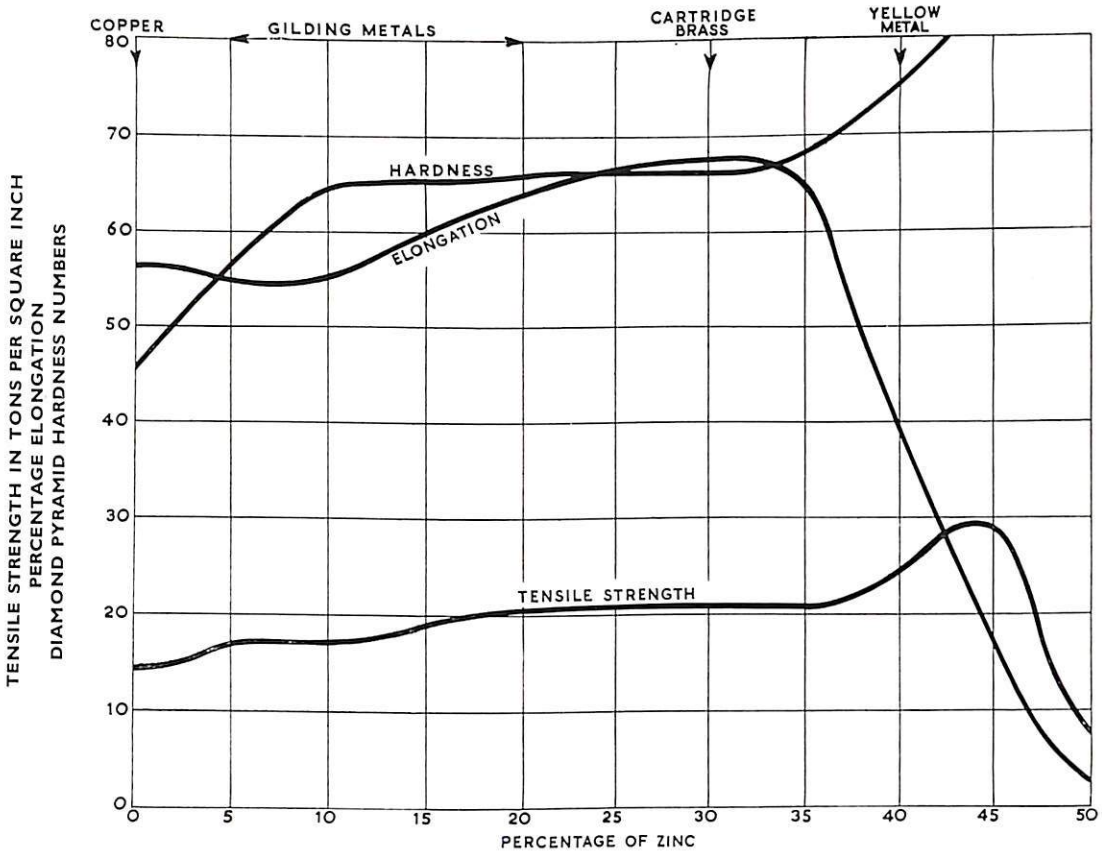
As has been indicated earlier, copper and an extensive range of copper alloys in strip and sheet form are used for the manufacture of various products and in the following pages some of the relevant properties of the more important of these materials are considered.

COPPER, GILDING METALS AND BRASSES.

The types and properties of copper, gilding metals and brasses are described in some detail in C.D.A. Publications No. 12, "Copper Data," No. 6, "Brasses," and No. 43, "Copper and its Alloys in Engineering and Technology." A comprehensive review will therefore not be made in this book, but, in order to illustrate the range of properties of the copper-zinc alloy series, some values of hardness, tensile strength and elongation of strip and sheet material are shown graphically on page 56. This clearly shows the hardening and strengthening which result from increasing zinc additions to copper. Ductility, as measured by elongation, is also at first progressively improved, reaching a maximum when the copper content is about 70 per cent., but when this figure is reduced, the ductility is rapidly impaired.

Copper.

Several grades of copper are recognised, all of which are used to some extent for press and other metal working operations. The principal forms are *high conductivity* copper of the *tough pitch* type and *phosphorus deoxidised* copper, which may be either arsenical or non-arsenical. The mechanical properties of these various forms of copper are very similar—namely about 15 tons/sq. in. and up to 25 tons/sq. in. tensile strength in the annealed and hard rolled conditions respectively —but the deoxidised and oxygen-free forms of copper withstand more severe cold working than the tough pitch varieties, and are preferred for certain deep drawing and spinning operations; deoxidised copper should also be used for autogenous welding. The electrical and thermal



MECHANICAL PROPERTIES OF ANNEALED COPPER-ZINC ALLOYS

conductivities vary very much with the purity of the copper, and for applications involving high conductivity it is necessary to specify "High Conductivity" copper.

Although copper is initially much softer than any of the copper-zinc alloys it does not possess such high ductility or strength and therefore requires more care in operations such as pressing, in which the metal is subjected to high tensile stresses. On the other hand, copper does not work-harden so rapidly as brass and it may be subjected to a considerable amount of deformation without the necessity for annealing; it lends itself especially to working processes which tend to compress or "iron" the metal, such as coining and spinning.

It should be emphasised that when any of the varieties of copper is required for the manufacture of products the final appearance of which is of importance and which need to be polished, or again, when heavy amounts of deformation by drawing or spinning are necessary in manufacture, then *cold-rolled* and *annealed*, rather than *hot-rolled*, strip or sheet should be specified. *Hot-rolled* strip and sheet possess a rougher matt surface and are widely used for certain products, such as the bodies of water storage cylinders and tanks, chemical and industrial plant. Rolled copper sheet and strip for general purposes are the subject of British Standard No. 899.

Gilding Metals.

Although the gilding metals normally range in composition from 80 to 95 per cent. copper and usually contain 85 or 90 per cent., yet occasionally alloys of still higher copper content are encountered, as for instance the 97 per cent. copper, 3 per cent. zinc alloy used for caps of cartridges and which is commonly known as cap copper. Owing to their attractive golden colour the principal application of the gilding metals is for decorative purposes, although they may be used in other cases where a low work-hardening rate is desirable. British Standards Nos. 711, 712 and 713 deal with gilding metals of 80, 85 and 90 per cent. copper content respectively.

70/30 Cartridge Brass.

As may be seen by reference to the graph on page 56, 70/30 brass combines optimum ductility with good strength, so that it is largely

used for articles the production of which necessitates very heavy amounts of deformation; on this account 70/30 brass is one of the best known materials for deep drawing and other metal working operations. For such purposes it is mostly used in the softened condition, but it is also available in a range of tempers, thereby fitting it for applications where hardness or springiness is essential. The tensile strength may vary from about 20 to about 45 tons/sq. in. and the Diamond Pyramid hardness from about 55 to about 200, depending upon the amount of cold work. The British Standard for 70/30 brass strip and sheet is No. 267.

65/35 Brass.

This is a cheaper grade of material, which possesses quite appreciable ductility, as it is still well within the alpha range; the properties may be taken as being rather similar to those of 70/30 brass. British Standard No. 266 is concerned with this material in sheet and strip forms.

Basis Brass.

This grade contains from 61·5 per cent. to 64 per cent. copper and is the cheapest form of brass which is in general suitable for cold working operations. British Standard No. 265 deals with this material.

Yellow metal or Muntz metal.

This contains 60 per cent. copper, 40 per cent. zinc, and although it is unsuitable for pressing and similar modern metal working operations, yet yellow metal is of great importance in Eastern countries for the production of various articles by hand fabrication. Yellow metal is, however, used in applications which do not call for good cold working properties and where surface appearance is not a matter of importance. It usually has a somewhat rough surface since it is rolled hot in the course of manufacture. Yellow metal in plate, sheet and strip forms is dealt with in British Standard No. 264.

Brasses with small additions.

The foregoing grades represent the most common forms of the copper-zinc alloys, but there are a number which contain additions of other elements such as aluminium, iron, nickel, silicon, tin and arsenic, resulting in alloys of special corrosion resistance or which are amenable to hardening by heat treatment. "Kunial," a proprietary alloy, is

such a heat-treatable brass and an interesting application is shown on page 18. This material offers considerably fewer fabrication difficulties than such alternatives as, for instance, stainless steel, and even at elevated temperatures which would soften a straight brass, remains sufficiently tough to withstand normal usage.

The addition of lead to brass deserves special mention. It results in a great improvement of machining properties, but there is unfortunately a considerable sacrifice of ductility. Leaded brass is available in both sheet and strip forms, the compositions usually being about 63 per cent. copper, 0·5 or 1·5 per cent. lead, balance zinc.* These brasses are used mainly for articles which require engraving, such as name plates and measurement rules, although they are also used for components of clocks and similar apparatus, the manufacture of which necessitates many notching and perforating operations, the leaded brasses being particularly suited for shearing. Owing to their relatively low ductility and impact properties, leaded brasses are unsuitable for severe bending or forming operations, although the 0·5 per cent. lead alloy offers a good compromise in regard to working and machining properties.

MECHANICAL PROPERTIES.

Graphs illustrating the relationship of mechanical properties and amount of work by cold rolling for 70/30 brass strip and 90/10 gilding metal, have been given on pages 12 and 13 of C.D.A. Publication No. 6, "Brasses," and these show the range of properties which it is possible to obtain by cold working these two alloys. Similar information for H.C. copper strip will be found on page 7 of C.D.A. Publication No. 12, "Copper Data."

Although many mechanical tests are employed for specification and control of strip and sheet material the hardness test is most widely used, as a knowledge of the hardness, together with grain size, generally affords sufficient information concerning the properties of strip and sheet material required for metal working operations. However, other tests, which attempt to reproduce the treatment to which the material will ultimately be subjected, are also largely used; amongst

* B.S. 2785

these there are various forms of bending and ductility tests, but universal agreement regarding standardisation of such tests has not been reached. The best known is the Erichsen cupping test, for it is both simple and informative, the depth of the cup being related to elongation, while the relative roughness of the " dome " gives an impression of the grain size, so that both the drawing properties and the subsequent surface appearance of the products can be assessed. There are in addition many other forms of cupping tests.

Hardness.

This property may be determined by several different methods, but the most reliable results are generally given by the Diamond Pyramid test, which has the added advantage that it can be applied to thin strip. (See British Standard No. 485, *Tests on Thin Metal Sheet and Strip.*) For 70/30 and similar brasses, the hardness values encountered upon strip and sheet intended for the applications indicated are of the order given below.

Diamond Pyramid Hardness	*Applications*
55–75	In annealed condition for deep-drawn and other heavily worked products; the lower hardness values are encountered when the grain size is large and *vice versa* (see page 61).
80–100	For pressings in which slight additional " rigidity " is advantageous.
100–120	For shallow pressings, particularly those of large diameter.
120–160	For various formed components where " rigidity " is essential.
160–180	For components which are subjected to right-angled bends, both in the direction and across the direction of rolling.
180–200	" Spring-hard " brass for components which are subjected to right-angled bends across the direction of rolling only.

The above figures are only intended to be an approximate guide, and users are urged wherever possible to submit samples to manufacturers rather than to specify a hardness range of a given "temper" condition.

Grain size.

Both grain size, which can be determined by metallographic examination, and hardness depend largely upon annealing temperature, conditions of working and composition of the brass. Although generalisation on the relationship between hardness and grain size of annealed brass is dangerous, it may be stated that average grain sizes of 0·03 mm., 0·05 mm. and 0·10 mm. usually correspond with D.P. hardnesses of about 75, 65 and 55 respectively.

A generally accepted principle has been that the larger the grain size the better the ductility and consequently the cold working properties. But when smoothness of the final product is essential and polishing costs must be low, the grain size should be restricted to 0·04 mm. or less. Furthermore, advantages seem to accrue when copper alloys of considerably smaller grain size are used. For instance, Walker and Craig[79] have demonstrated the beneficial effects of very small grain size on the mechanical properties of deep drawing brass and particularly on the fatigue strength. An extremely rapid continuous annealing method which is claimed to produce very small grain size together with an overall improvement in cold working properties has been described by Turner and Banno.[81]

Erichsen Cupping Test.

In view of the widespread use of this test for the control of strip material for pressworking operations, some typical values for 70/30 brass are given below. It should, however, be appreciated that results obtained upon any one particular machine cannot with certainty be related to those from another machine of the same type. Hence the quoted values should be regarded only as comparative among themselves.

Condition	Erichsen. Depth of cup (mm.)		Diamond Pyramid Hardness
	Thickness of Strip		
	0·060 in.	0·020 in.	
Annealed	14·5	12·5	65
Rolled 10 per cent. reduction ...	12·0	10·0	90
Rolled 30 per cent. reduction ...	9·0	7·0	140
Rolled 60 per cent. reduction ...	4·5	4·5	175

TIN BRONZES AND PHOSPHOR BRONZES.*

These are essentially copper-tin alloys containing additions of phosphorus, generally of the order of 0·1 per cent. Three grades of phosphor bronzes—in strip and sheet forms—are recognised in B.S. No. 407 (1939), covering a range of alloys containing 3–7½ per cent. of tin and 0·02–0·4 per cent. of phosphorus. These alloys possess excellent resistance to corrosion. In the annealed state, the tensile strength of phosphor bronze is about 25 tons/sq. in. and may exceed 55 tons/sq. in. in the hard condition. Increasing tin content leads to harder and stronger alloys.

Of particular importance are numerous types of springs, bent from bronze strip which may be supplied in a range of tempers suitable for the amounts of work involved. For bent products in which the angle of bend is small, not exceeding 90° across the direction of rolling, strip possessing a tensile strength of about 50 tons per sq. in. may be used; for bent products in which the bending is more severe, including bends of 90° in the direction of rolling, the tensile strength of the strip should be somewhat less. (See C.D.A. Publication No. 39, "Copper and Copper Alloy Springs.")

A British coinage alloy has a composition of 95·5 per cent. copper, 3 per cent. tin, and 1·5 per cent. zinc, and hence comes into the category of bronzes.

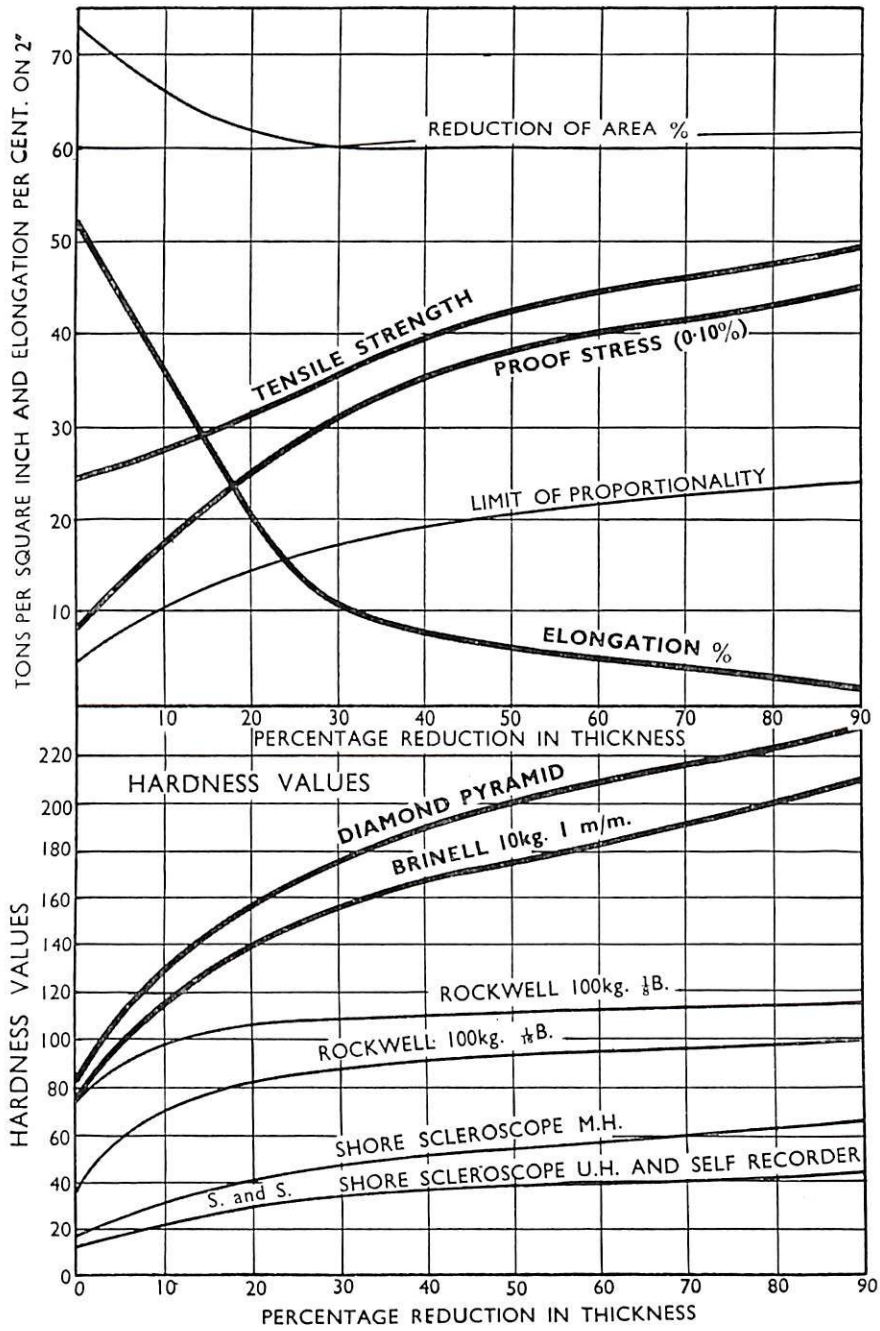
NICKEL SILVERS.

Whereas at one time an extremely wide range of compositions was encountered, the nickel silvers are now standardised in British Standard No. 790 (1938) into seven groups with nickel contents of 10, 12, 15, 18, 20, 25 and 30 per cent.; the copper content being maintained at either 55 to 60 per cent. or 60 to 65 per cent., the remainder being zinc.

The addition of lead in amounts of 1 to 2 per cent. may be made to the alloys of 12 to 18 per cent. nickel content, so as to provide good machining characteristics, and these alloys are used in the manufacture of key blanks and general notched and engraved products. As the nickel content is increased, so the colour changes from a very pale yellow to silvery white; at the same time the corrosion and tarnish-resisting properties are improved. The most widely used nickel

* See also C.D.A. Publication No. 43, "Copper and its Alloys in Engineering and Technology."

EFFECT OF COLD ROLLING ON MECHANICAL PROPERTIES OF NICKEL SILVER STRIP (62%Cu, 18%Ni, 20%Zn)



silvers are those of 15–18 per cent. nickel content, as these possess a satisfactory white colour, good mechanical and corrosion-resisting properties and are cheaper than the alloys of higher nickel contents.

The nickel silvers in strip and sheet forms are used in a wide range of industries; some of the more important products are spoons and forks, imitation jewellery, military and other badges, plumbing and architectural fittings, key blanks and miscellaneous accessories for the automobile trades. Nickel silver is generally used as the basis material for silver or nickel electroplated table and other ware, the alloys with higher nickel content being used for the best quality products. A further important application of nickel silver strip is in telephone equipment, where it is used for a variety of contact and other springs. (See C.D.A. Publication No. 39, " Copper and Copper Alloy Springs.")

The tensile strengths of the above nickel silvers in the annealed state range from about 25 tons/sq. in. to 30 tons/sq. in. and may be increased by cold rolling to upwards of 45 tons/sq. in. The graph on page 63 shows the change in the mechanical properties of 18 per cent. nickel silver strip by cold rolling.[76]

In addition to the above nickel silvers, there is a further type having an approximate composition of 45 per cent. nickel, 23 per cent. zinc, the balance being copper, together with small additions of iron, manganese and other impurities; this alloy in strip and sheet forms is defined in Ministry of Supply, Aircraft Material Specifications, D.T.D. 232 and D.T.D. 237. The tensile strength in the annealed condition is required to be at least 35 tons/sq. in. and in the hard-rolled condition it may be within the range of 50–65 tons/sq. in.

CUPRO-NICKELS.

Perhaps the best-known cupro-nickel alloys have compositions of 80 per cent. copper, 20 per cent. nickel, 75 per cent. copper, 25 per cent. nickel, and 70 per cent. copper, 30 per cent. nickel. Sheet and strip of these compositions are covered by B.S. No. 374.

The former is best known on account of its use for bullet envelopes. The choice of cupro-nickel for this purpose is mainly on account of its excellent cold-working properties, these permitting the manufacture of bullet envelopes from strip without any annealing operations;

further advantages are that cupro-nickel, on account of its softness, does not injure the rifling of the barrels; moreover it does not seriously "foul" the latter. In the form of both strip and sheet, the 80/20 alloy is used also for a variety of other products which call for a ductile material, while further applications are for plant and apparatus required to withstand corrosive conditions.

The 75/25 alloy is widely used for coinage purposes, as it possesses a silvery white colour and good ductility.

For corrosion resistance purposes, the 70/30 alloy is widely favoured, and tubes, tube plates and fittings of marine and other condensers are frequently made of this material. Alloys of a higher nickel content—such as the 55 per cent. copper, 45 per cent. nickel alloy—are used as resistance materials for electrical apparatus and also for decorative and other architectural applications. The properties of these materials, and those of still higher nickel content, fall, however, outside the scope of this book.

Typical values for the mechanical properties of 80/20 cupro-nickel sheet in various rolled conditions are given in the following table, and these results show very clearly the comparatively low rate of work hardening which is encountered in this material.

Condition	Diamond Pyramid Hardness	Tensile Strength tons/sq. in.	Elongation per cent. on 2 in.
Cold rolled and annealed ..	75	22	45
Cold rolled 10 per cent. reduction	103	26	28
Cold rolled 30 per cent. reduction	150	33	10
Cold rolled 60 per cent. reduction	165	35	5
Cold rolled 75 per cent. reduction	167	36	4
Cold rolled 90 per cent. reduction	170	38	4

70/30 cupro-nickel is a little harder in all conditions than 80/20 cupro-nickel and the tensile strength may range from 25 tons/sq. in. to upwards of 40 tons/sq. in., depending upon the amount of cold work.

ALUMINIUM BRONZES.*

These alloys are usually considered as falling into two groups, one of which contains approximately 4 to 8 per cent. of aluminium and the other 9 to 11 per cent. of aluminium. The first group is characterised by good cold-working properties and is of the alpha type, while the second group is best worked in the hot condition and is structurally of a duplex type.

The alpha alloys of 4 to 8 per cent. aluminium content are occasionally used, in the form of rolled strip and sheet, for the production of certain components required to have special properties. Their mechanical properties are superior to those of the alpha brasses, both in annealed and worked conditions, as will be seen by reference to the data included in the table on page 73. In general, the alloys possess good resistance to corrosion and also to oxidation at elevated temperatures, while amongst their other attributes are good strength, a pleasing golden colour, and good resistance to tarnishing influences. However, owing to the presence of surface oxides, there may be scoring troubles when drawing these alloys.

The alloys containing aluminium in amounts of 9 to 11 per cent. are widely used in the form of hot rolled sheet and strip for the construction of chemical and related plant, such as pickling crates. These duplex aluminium bronzes, which frequently contain also additions of iron, manganese or nickel, are much harder and stronger than the alpha alloys, and in the form of hot rolled sheet generally have a tensile strength exceeding 40 tons/sq. in. ; when containing considerable quantities of additional elements, much greater strengths can be obtained.

SILICON BRONZES.

These alloys were first used commercially for chemical plant required to possess great strength and superior corrosion-resisting properties. Copper-silicon alloys containing minor proportions of manganese, iron, zinc, tin, aluminium and other elements have been

*See also C.D.A. Publication No. 31, "Aluminium Bronze."

developed under a variety of trade names, of which the best known are perhaps " Everdur " and " P.M.G. Metal."

The silicon content of commercial alloys is limited to less than 4 per cent., as with greater amounts there are difficulties in fabrication by either hot or cold working processes. The quantities of the additional elements which are present in commercial silicon bronze are as a rule limited to less than 1 per cent. Such alloys in the cold-worked condition provide the engineer with materials having the strength of steel combined with excellent corrosion resistance; their welding properties are admirable and owing to their low thermal conductivity it is possible to weld economically by electric arc methods.

The tensile strength of silicon bronzes in strip form ranges from about 25 tons/sq. in. in the annealed condition to upwards of 45 tons/sq. in. when hard rolled. They usually possess excellent resistance to corrosion fatigue.

BERYLLIUM COPPER.*

The addition of beryllium to copper provides a series of alloys with extremely interesting properties, of which engineers are tending to take increased advantage, though the price is such that the alloys can only be considered for special applications, such as pressure-responsive diaphragms, flexible bellows and small springs.

When beryllium is present in certain amounts—usually of the order of 2·0 per cent. to 2·5 per cent.—the alloys may be hardened by heat treatment and this is the particular feature possessed by them. As quenched from temperatures of the order of 800° C. the alloys are soft and can be cold worked by the usual fabricating processes. Reheating to temperatures of 300° C. to 350° C., depending upon condition and actual composition, results in an increase of hardness and strength of much greater magnitude than is experienced with any other known alloy, non-ferrous or ferrous; at the same time there is an improvement of thermal and electrical conductivity. The improvement of mechanical properties will be appreciated from the tests upon alloys of 1·75 per cent. to 2·5 per cent. beryllium content, given on page 68.

* Further information on this alloy is contained in C.D.A. Document No. M.49, "Beryllium Copper."

Condition	Limit of Proportionality	Proof Stress, 0·1% permanent set	Tensile Strength	Elongation	Diamond Pyramid Hardness
	Tons/sq. in.	Tons/sq. in.	Tons/sq. in.	Per cent on 2"	
Quenched from 800° C. ..	4– 8	8–12	30–35	40–50	100–120
Quenched as above and reheated to 250° C.–325° C. ..	30–40	40–60	70–80	4– 7	320–380
Quenched as above, cold rolled and reheated to 250° C.–325° C.	35–50	50–70	80–90	2– 4	360–420

MISCELLANEOUS MECHANICAL AND PHYSICAL PROPERTIES OF COPPER ALLOYS.

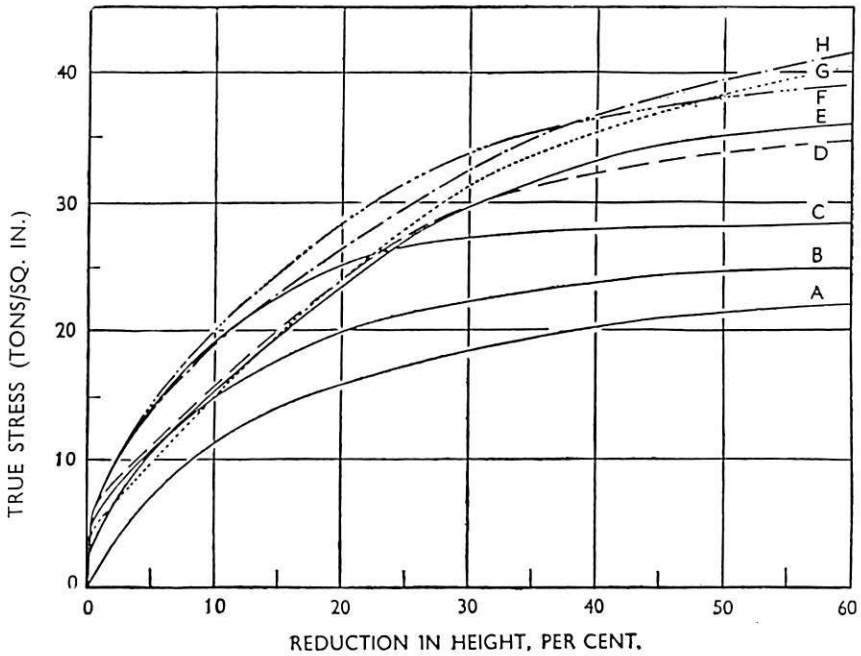
In the table on page 73, some of the principal properties of the group of copper alloys, which are chiefly used in strip and sheet forms, are summarised.

The figures quoted as endurance limits are only given as typical of the various materials; the results have, in fact, been taken from various published sources and in some instances considerable divergence of opinion exists. It may be pointed out that in almost every case it is possible to obtain slightly higher endurance values of the work-hardened materials by a low-temperature heat treatment.

Comparison of the behaviour of different copper alloys under cold deformation can be made from the curves reproduced on page 69. The diagram has been taken from the researches of M. Cook and E. C. Larke[77] and shows the compressive stresses required to produce deformations of up to 60 per cent. for certain copper alloys most frequently used for presswork. Special methods of testing and calculation ensured that the deformation represented by the curves was uniform throughout the whole of the material.

The true stress required to deform copper by 60 per cent. was 22 tons/sq. in., while for phosphor bronze 42 tons/sq. in. was necessary. The curves for the other alloys fall between these extremes.

COMPARISON OF THE BEHAVIOUR OF DIFFERENT COPPER ALLOYS UNDER COLD DEFORMATION



Homogeneous Compression Curves for Copper Alloys.

Deformations are expressed in terms of the percentage decrease in height of a cylinder under uniform compression.

To obtain the " true " stresses used in the diagram, the load is divided by the sectional area of the deformed specimen, i.e. the area which is actually carrying the load at each instant of the test. These true stresses must not be confused with the nominal stresses of ordinary tensile and compression tests, which are calculated upon the original sectional area before deformation.

Curve A. Tough Pitch High Conductivity Copper.
,, B. 90 : 10 Gilding Metal.
,, C. 80 : 20 Cupro-Nickel.
,, D. 70 : 30 Brass.
,, E. 64 : 36 Brass.
,, F. Nickel Silver, 18 per cent. nickel.
,, G. Aluminium Bronze, 5 per cent. aluminium.
,, H. Phosphor Bronze, 5 per cent. tin, 0·25 per cent. phosphorus.

(Reproduced by courtesy of the Institute of Metals.)

The significance of the term "work hardening rate," which has been used more than once in this book, becomes clearer in the light of this diagram. It refers to the steepness, or "slope," of the curves, especially in the range of reductions between about 20 per cent. and 60 per cent., which are so important in press work. Thus the curve (C) for cupro-nickel shows that no more stress need be used to deform this material by 60 per cent. than by 30 per cent., a clear indication of its special suitability for deep drawing. Copper (A) and gilding metal (B) also have low work-hardening rates, and are easily handled in presses, while the greater difficulty experienced with aluminium bronze and phosphor bronzes is shown by the much greater steepness of their deformation curves (G and H).

COMMERCIAL SIZES OF SHEET, STRIP AND FOIL.

Sheet

The description "sheet" is generally applied to flat material which is over 18 ins. wide and cut to exact length, the thickness being over 0·006 in. but not over 0·375 in. The most popular size of sheet is 4 ft. by 2 ft. but sheets can normally be obtained in widths up to and even exceeding 4 ft. and lengths up to 12 ft., according to the thickness.

Strip and Foil.

By definition, strip is material the thickness of which ranges from over 0·006 in. up to and including 0·375 in., whereas foil is material 0·006 in. thick and under. Strip and foil are generally supplied in coils or rolls where gauge permits, but may also be flat or folded. The widths may range up to 24 ins. or even more in special cases.

The widths in which strip and foil are obtainable are to some extent dependent on thickness. In gauges down to about 0·004 in. there is little difficulty in obtaining 12-in. widths, but in still thinner gauges, the maximum width normally available is about 6 ins.

The weight of coils may range from a few pounds to several hundredweights and their length depends on the width and thickness of the strip or foil. By way of example, copper strip 12 ins. wide by 0.048 in. thick would probably be supplied in coils about 50 ft. in length. Specially heavy and long coils can be obtained by strip users who have

suitable handling facilities. The prices of strip depend on the dimensions, extra being charged as the thickness is decreased and when the strip is unusually wide or narrow.

Commercial tolerances.

Both strip and sheet can, if necessary, be supplied to extremely accurate dimensional tolerances as necessitated, for instance, in the case of strip for coin manufacture. However, it is customary for the tolerances on strip and sheet to be in accordance with the provisions of B.S. No. 266 (1936), as summarised below.

The tolerance on the length of sheet, or of strip "cut to length," is $\pm \frac{1}{16}$ in. for lengths up to 4 ft.; $\pm \frac{1}{8}$ in. for lengths of 4 ft. to 8 ft.; $\pm \frac{1}{4}$ in. for lengths exceeding 8 ft.

The tolerance on width is $\pm$ 0·025 in. for material not exceeding 6 ins. wide; $\pm$ 0·032 in. for widths of 6 ins. to 12 ins.; $\pm$ 0·0625 for widths exceeding 12 ins. Generally, however, manufacturers conform to very much closer tolerances, and, for instance, in the case of thin strip, of less than about 0·042 in. thickness, it is usual for the tolerance limits to be less than half the above values.

The tolerance on thickness varies very much with the dimensions of the strip or sheet and the following examples from B.S. No. 266 (1936), have been selected to illustrate this:—

Width (ins.)	Thickness (in.)	Tolerance on Thickness (in.) Plus or Minus
Up to 6	Under 0·010	0·0005
6 to 12	0·010 but under 0·024	0·0015
12 to 24	0·024 but under 0·040	0·0025
24 to 42	0·040 but under 0·080	0·0035

Condition of edges of sheared strip.

Unless otherwise specified it is conventional for strip to be sheared to the necessary width after the final rolling and annealing operations. This is generally the most satisfactory procedure, as the edges are then in a slightly hardened condition and there is less possibility of damage

in transit, etc., so that continual feeding operations on presses and other machines proceed more smoothly. In certain operations, particularly those involving stretching and bending, as in the forming of the spiral strip on the tube heater element illustrated on page 35, the presence of hardened edges is objectionable and in these somewhat rare circumstances it is advisable to specify metal to be annealed after shearing.

Shearing adversely influences elongation values as determined upon tensile test pieces, and this fact should be borne in mind when drawing up specifications for the properties of narrow strip and also when conducting tests on such material; the removal of hardened sheared edges by milling or filing, followed by polishing with emery cloth, will give more correct elongation values, but even then the effects of edge condition cannot always be entirely disregarded.

COMPARATIVE PROPERTIES OF COPPER AND COPPER ALLOY SHEET OR STRIP

	High Conductivity Copper	Deoxidised Non-arsenical Copper (0·04% P)	Gilding Metal 90% Cu 10% Zn	Cartridge Brass 70% Cu 30% Zn	Basis Brass 63% Cu 37% Zn	Phosphor Bronze 95% Cu 5% Sn	Nickel Silver 62% Cu 18% Ni 20% Zn	Aluminium Bronze 95% Cu 5% Al	Cupro-Nickel 80% Cu 20% Ni
Tensile Strength—									
Cold rolled and annealed (tons/sq. in.)	14	14	18	21	22	23	24	25	22
Cold rolled* (tons/sq. in.)	24	24	29	37	38	43	43	45	34
Proof Stress (0·1 per cent)—									
Cold rolled and annealed (tons/sq. in.)	4	4	5	6	6	8	8	8	7
Cold rolled* (tons/sq. in.)	20	20	26	31	32	38	38	39	29
Elongation—									
Cold rolled and annealed (%) ..	55	60	55	70	55	65	52	70	45
Cold rolled* (%)	8	8	7	8	8	8	6	8	8
Modulus of Elasticity ($\times 10^6$ lb./sq. in.)	18	18	17	15	15	16	19·5	18	19·5
Approximate Endurance Limit (50×10^6 cycles)									
Cold rolled and annealed (tons/sq. in.)	5	5	5	6	7·5	10	10	—	7·5
Cold rolled* (tons/sq. in.)	6·5	8·5	8	10	10	12	—	—	12
Electrical Conductivity (% I.A.C.S.)	100	80	43	27	27	16	6	17	6
Thermal Conductivity (cals./sq.cm./cm./sec./°C. at 20° C.)	0·92	0·75	0·45	0·29	0·29	0·18	0·08	0·19	0·08
Thermal Expansion ($\times 10^{-6}$ per °C. in range 20° - 110° C.)	16·6	16·6	17·5	19	19·7	17	14·8	17	15·5
Density (c.g.s. units)	8·93	8·93	8·80	8·51	8·42	8·90	8·72	8·15	8·96
Melting Point or Range (° C)	1083	1080	1020–1045	920–955	900–910	920–1060	1050–1110	1055–1070	1130–1190

* Cold rolled about 50 per cent. reduction of thickness.

GAUGE, THICKNESS, AND WEIGHT PER SUPERFICIAL FOOT OF BRASS AND COPPER STRIP AND SHEET

(Calculated on the basis of brass at 534 lb. per cubic foot and copper at 558 lb. per cubic foot.)

Imperial Standard Wire Gauge	Thickness in.	Brass lb.	Copper lb.	Imperial Standard Wire Gauge	Thickness in.	Brass lb.	Copper lb.
1	0·300	13·350	13·950	22	0·028	1·246	1·302
2	0·276	12·282	12·834	23	0·024	1·068	1·116
3	0·252	11·214	11·718	24	0·022	0·979	1·023
4	0·232	10·324	10·788	25	0·020	0·890	0·930
5	0·212	9·434	9·858	26	0·018	0·801	0·837
6	0·192	8·544	8·928	27	0·0164	0·729	0·762
7	0·176	7·832	8·184	28	0·0148	0·658	0·688
8	0·160	7·120	7·440	29	0·0136	0·605	0·632
9	0·144	6·408	6·696	30	0·0124	0·551	0·576
10	0·128	5·696	5·952	31	0·0116	0·516	0·539
11	0·116	5·162	5·394	32	0·0108	0·480	0·502
12	0·104	4·628	4·836	33	0·0100	0·445	0·465
13	0·092	4·094	4·278	34	0·0092	0·409	0·427
14	0·080	3·560	3·720	35	0·0084	0·373	0·390
15	0·072	3·204	3·348	36	0·0076	0·338	0·353
16	0·064	2·848	2·976	37	0·0068	0·302	0·316
17	0·056	2·492	2·604	38	0·0060	0·267	0·279
18	0·048	2·136	2·232	39	0·0052	0·231	0·241
19	0·040	1·780	1·860	40	0·0048	0·213	0·223
20	0·036	1·602	1·674	41	0·0044	0·195	0·204
21	0·032	1·424	1·488	42	0·0040	0·178	0·186

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